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SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE

OF THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

SECOND SESSION

ON

NASA'S SPACE SCIENCE AND APPLICATIONS PROGRAMS

MARCH 7, 1988

PART 1

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MONDAY, MARCH 7, 1988

U.S. SENATE,
SUBCOMMITTEE ON SCIENCE, TECHNOLOGY, AND SPACE,
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Boston, Mass.

The subcommittee met at 9:35 a.m. in the Cahners Theatre, Boston Museum of Science, Science Park, Boston, MA, Hon. John Kerry [presiding].

Staff members assigned to this hearing: Marty Kress; Penny Dalton, professional staff members; and Pete Perkins, minority professional staff member.

OPENING STATEMENT BY SENATOR KERRY

Senator KERRY. This hearing of the Science, Technology, and Space Subcommittee will come to order.

Ladies and gentlemen, if you notice that the clock is going to be frozen at 9:30, that is because when you are having a good time time stands still.

Senator KERRY. It is going to stay that way throughout, I am told. So your private watches will be accurate.

I am delighted to welcome you here on behalf of the United States Senate and also on behalf of all those who are deeply interested in the topic that we are going to learn about and discuss today.

I am also very pleased to preside at a hearing at which I think we are going to learn something about the scope and the direction, the health and the wellbeing of our nation's space and technology program, and we are going to learn it from a very distinguished group of witnesses.

I would like to thank the staff, and particularly the director of the Museum, for their accommodating us this morning. We have already had a breakfast here and now we are using the Cahners Theater, for which we are very, very grateful. And I cannot think of a more appropriate place to have this hearing than to have it here.

Also, I am particularly perhaps even overwhelmed is a better way to express it, but delighted at the response that we have had to the notification about this hearing. We have had many, many more people ask to testify than we have been able to accommodate in the course of one morning's testimony.

And I can tell you, the one thing I will guarantee you is that when I return to Washington I will recommend to our Chairman, Senator Hollings, that Boston be put on next year's calendar for another field hearing, in which I think we can go even further and we will have the time to be able to go today.

I think it is fair to say—many of you are aware of this, were aware of this before you came here today, but I think it is fair to say that our nation's space program is without any question at a very critical juncture right now.

All of us have become aware of the vision and the scope of the Paine Commission report and the Dr. Sally Ride report. On the other hand, we have also become aware of last year's budget agreement and of the constraints that we have in terms of expenditures and the national budget.

The subcommittee has come to Boston to try to explore the critical issues regarding our space technology applications program and to try to involve the science community and New England in the debate over our future and the scope and the direction of that space program, and particularly the space science part of it.

We are honored to have Dr. Leonard Fisk, Associate Administrator of NASA, here with us today, as well as Dr. Mary Cleave, also with NASA and an astronaut. And we will hear them highlight the NASA space science and applications budget request, as well as the critical choices that need to be made in 1988.

And Dr. Cleave will present a practical applications of space technology presentation, I believe a slide presentation, which we will all share. Then we are going to have a panel of distinguished academicians from the Boston area who will discuss the relationship of the civil space program to their activities, to space science, global change, automation and robotics, space technology, and that relationship to the wellbeing of their university infrastructure and graduate programs, and finally to the competitive posture and technological leadership of the United States.

Finally, we will hear from three different kinds of experts, three young students—Rashawn Seams, Pamela Gay and Mark Gannon—who are students from the Boston area who will discuss their views of the space program and its relationship to their lives and their educational process.

Every single one of us in this room in one way or another has shared an extraordinary part of our lifes with America's scientific and technological prowess. It has been a critical element of our nation's success. And the spinoffs from the civil space program, many of them unforeseen and some of them foreseen, have become commonplace elements of our lives.

The advantages which we enjoy in computers and satellite communications, in medicine, weather forecasting, aeronautics, are the direct results of research and development activities that were sponsored by NASA. Whether you are an engineer or a scientist or a reporter or a student or a housewife or a sports buff, space age technology has been a part of our daily lives.

Just recently at the Olympics, we actually saw part of the Olympics and our TV screens were a manifestation of the communications technology itself.

In addition, Alberto "La Bamba" Tomba skiied to a gold medal wearing clothing and on skis that were developed partly from space age technology.

The United States America's Cup entry, the *Stars and Stripes*, was a hull that was pieced together partly through space age technology. Microwaves and teflon have become almost buzzwords of the linkage of daily lives to space age technology.

Applications of space age technology have helped individuals with disabilities, in the areas of housing, employment, transportation, and recreation, and it has helped students and educators throughout the world. Ongoing research in materials processing and microgravity have led to improved manufacturing processes and offer the potential for significant advancements in semiconductors, optical systems technology, pharmaceuticals, and biotechnology.

And there are more advantages, extraordinary advantages in the works, and we will hear today of some of those that have applications which will significantly improve the quality of life for all mankind and hopefully the competitive posture of this country.

Our challenge in the Congress is to be able to provide the resources that are required to take advantage of these opportunitie, to provide the budgetary support to implement these visions.

But we are also going to need the help of all of our citizens. People are going to have to share in the vision and understand that we have to reach beyond our daily lives and beyond our daily demands of paying bills and sending kids to school and meeting a mortgage and so forth.

To understand this vision of the future is going to require an investment in that future.

I have talked about things that are tangible. Obviously, there is much in space exploration that is intangible. It is just part of our spirit as human beings and part of our exploratory need.

I think that is almost equally as important a part of what we are about in this effort, and hopefully today's is going to help us to understand and touch that vision a little bit more, so that we will be willing to run the risks and place our bets, in a sense, in the future.

In addition, obviously, recently with the meeting of Secretary Gorbachev and President Reagan in Washington, there was a cooperative agreement that was reached with respect to joint efforts in terms of understanding Earth better and understanding the climatic changes and the shifts that the current rate of industrialization has placed on us as human beings.

That is a very important part of space applications and technology and research. As we will hear from our scientists today, nothing better provides the laboratory for understanding where we come from and where we are going than to be able to conduct those experiments where it all happened and still happens.

That means in space itself. And we have much to learn about ourselves in order to be able to understand where we are going. So whether it is a matter of global climatic change, whether it is the greenhouse effect, whether it is acid rain, whether it is ozone depletion, there are a host of issues, I think, on which our future is already staked. And we need to join into that stake ourselves by understanding the importance of putting our money where that future is.

I am delighted to welcome our first panel. We are going to do this in three panels. I will ask questions of each of them as we go along.

Our first panel is our NASA panel, and I hope you will all join me in welcoming Dr. Mary Cleave and Dr. Lennard Fisk, who have joined us from NASA. We are delighted to have you here with us. Thank you very much.

STATEMENT OF DR. LENNARD A. FISK, ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE AND APPLICATIONS, NASA

Dr. FISK. Senator, I am very pleased to be back here in Boston. As some of you may know, up until last April, I just lived across the border in New Hampshire, and recently joined NASA last April. We, of course, considered Boston to be the center of many of our cultural and our scientific activities.

It is perhaps unwise for anybody to stand up here and predict the future. However, one prediction that I believe we can make with confidence is that the inexorable march of this civilization into space will continue and that it will grow in importance; and that ever more the criteria by which we will judge the importance of nations, their success, their economic security, the wellbeing of their people, will be their prowess in space.

We need to ask ourselves, of course, what the future holds for the United States in space. Nowhere in history is it written that the nation that has been first is guaranteed to remain first, and indeed history would tell you that leadership for a nation can be very fleeting.

The competition here is, of course, clear. The Soviets launched 90 satellites last year. They have a permanently manned space station in orbit about the earth and they have announced ambitious plans for the exploration of Mars.

The Europeans, through their European Space Agency, have a commitment from their government, an actual commitment to double their space budget by the mid-1990's. And the Japanese have an ambitious space plan which costs in excess of $25 billion.

We have enjoyed the lead in space, but now we are being seriously challenged. And indeed, it is up to us today to decide whether that challenge is going to be met.

I would suggest that the decisions that Congress is going to be asked to make this year and the Administration is going to be asked to make this year and over the next few years concerning the future of the United States civilian space program are decisions of historical proportion.

They are going to get looked back upon by future generations of Americans as decisions which either preserved our technological leadership in space and thus our national future or whether they were decisions which permitted the mantle of leadership to pass from us.

We should ask ourselves, of course, what role science is going to play in the space program. That is the subject of our discussion today. There are undoubtedly fields of research which are sufficiently developed and understood so that it is not necessary to spend a major portion of the effort pursuing the underlying science.

Space is not such a field. It is a scientific endeavor to understand the near space environment of the earth, which is where we are planning to live and to work. It is a scientific endeavor to explore the planets, their origin, their evolution, and thus the origin and evolution of the earth, and to assess the resources of planets for perhaps eventual human exploration and use.

It is a scientific endeavor to observe the universe in all its variations, its exotic objects, its strange conditions, and by doing so to understand the forces that control it. Those are the very same forces that control us here on earth.

They can work for us, can provide energy sources and exotic technologies not now dreamed of. It is a scientific endeavor to observe the earth from space with the global perspective that space can provide and to attempt to understand how we as human beings may be inexorably altering our global environment to our detriment.

It is a scientific endeavor to study basic physical, chemical, and biological processes in the microgravity environment of space, and by doing so to make dramatic improvements in commercially important processes here on earth.

Space research in general and space science in particular is a technology driver. It stretches the envelope, challenges us to develop technologies and to accomplish tasks we have never done before, and by doing so provide spinoffs to the general economy.

Now, the space science program of the United States has been delayed, but it is basically sound. The missions we had intended to fly in 1986 and beyond will be flown in 1989 and beyond. The Challenger accident resulted in a three year delay.

But when we do return to flight, we will once again reassert our leadership in space science. The issue today then is how to ensure that there are not further setbacks in space science and that U.S. leadership is preserved for the future.

The fiscal year 1989 budget for space science and applications, which is the one that is currently before Congress, contains five basic themes which are designed to preserve and to enhance U.S. leadership in space science:

First, it includes adequate funding to keep the ongoing flight programs on schedule for launch at the earliest possible time. It is important to realize, if you have been reading about the amount of growth that occurs in the national budget between 1988 and 1989, that the vast majority, some 90 percent of it, is required simply to complete the ongoing projects that have already been agreed to.

The converse is also true. That is if these funds—if that growth is not able to be provided because of budgetary limitations, there will be cancellations in major flight programs, with devastating impact on the research, and a major setback to U.S. leadership in space.

The second theme that runs through the budget is to propose funds to move boldly to preserve the leadership in the future. The major flight programs that are currently under way will all be launched by 1993. What we start today are the follow-on projects.

The converse here is true, as well. If we fail to start any flight project today, we generate a hiatus in the space science program in the mid-nineties. We have one today because of the Challenger accident. We could generate another one.

I find it somewhat embarrassing that X-rays from the recent supernova, which has been the most spectacular astronomical event in 400 years, were observed from the Russian space station and by a Japanese space science satellite, and not observed by a U.S. mission.

We invented the field of X-ray astronomy right here in Boston with the pioneering work of Bruno Rossi and Ricardo Giacconi and their colleagues at American Science and Engineering. Yet, today we have no U.S. X-ray mission flying. This is a situation we should not allow to continue.

The leadership initiative in the 1989 budget is a new start for a mission called AXAF, the advanced X-ray astronomical facility. It is the third of the great observatories, after the Hubble space telescope and gamma ray observatory.

AXAF has a resolution that is 100 times more sensitive than any previous or planned X-ray mission, and 1,000 times more capable for spectroscopy. It is a mission that will ensure U.S. preeminence in X-ray astronomy for decades to come.

It is a mission that is affordable. It costs $27 million in the first year. It is a great observatory and so its run-out costs are substantial. But nonetheless, it fits in a level budget for space science and applications in fiscal year 1990, the subsequent fiscal year, and beyond.

Projects like AXAF stir the imagination of our youth and they attract them into careers in science and engineering. We also need to be concerned, however, with the actual training of students in science and engineering at the graduate level, and here we need something in addition. We need projects which are simple, ones which take less time to build than an AXAF and which are buildable on a relatively short time scale.

The third theme in our budget is to provide these near-term flight opportunities in a program which is an augmentation to what is called the Explorer program, i.e. to open up a new class of Explorers, the so-called Scout class, which are small but capable, and can be built and flown in three years, which is a time contemporaneous with the time required for graduate education. They are ideal for the training of the next generation of scientis and engineers.

The fourth theme in the budget concerns space station. It is time to begin to build the instruments that will be flown on space station and to develop the fields that will use these instruments. There are two principal areas of research for which the manned space station is essential, and that is microgravity science, which is materials and fluids in low gravity, and life science, which is living things, including humans, in low gravity.

Both of these fields are laboratory sciences. They require people to use the instruments. You want to see how the sample is behaving. You want to make adjustments while the experiment is running to get the maximum out of the experiment.

So the issue then is time on orbit with people. The spacelab program gives you seven to ten days on orbit, perhaps up to 16.

There is currently discussion of something called a commercially developed space facility, which operating in a people-tended mode may be able to get you 20 to 30 days on orbit. And the space station gives you unlimited time on orbit.

The budget that is under discussion provides funds to build instruments for both microgravity and life sciences, which can be flown in systematic order on first Spacelab, perhaps the commercially developed space facility, and then transitioned to space station. By the time you get to space station, you have fully developed and tested instruments, but most important you have a fully developed research community with extensive experience in space.

Of particular significance in the budget are also funds to begin the selection of Earth science instruments for the polar platform of space station. This is the project that NASA is going to undertake called the Earth Observing System, and indeed it is probably one of the most significant projects that NASA will undertake in the next few years.

It will allow us from polar orbit to observe the global earth and to determine how we as humans are affecting our environment, perhaps to our irretrievable detriment.

The final theme in our budget concerns the research base, which is the foundation of all the programs. It is the basic support for instrument development, for theoretical studies, for data analysis, and for graduate education. It is the underpinning of the research community here in the Boston and Massachusetts and New Hampshire area and throughout the country.

NASA depends on its university research community, and there are several enhancements in this budget which are of particular interest to that effort. The budget that we are proposing does what it is supposed to do: It preserves and enhances U.S. leadership in space, and it says in a way that can yield no uncertainty that we consider that leadership in space for our nation is in our national interest, is essential to our national future, and that we are not going to let that mantle of leadership pass from us.

Thank you very much.

STATEMENT OF

DR. LENNARD A. FISK
ASSOCIATE ADMINISTRATOR
SPACE SCIENCE AND APPLICATIONS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. Chairman, Members of the Subcommittee:

I am pleased to be here to present the proposed FY 1989 budget for the NASA Space Science and Applications program. This is a year in which the Congress will make decisions on the space program of historical proportion. You will determine whether the nation will go forward with a civilian space program that is second to none, or whether our position of world leadership in space will be allowed to erode. The proposed space science and applications budget supports a balanced and effective program, which will ensure world leadership in key areas of space science and applications, as has been required by the Space Act of 1958, and by every Presidential space policy since, including the one recently announced by President Reagan.

There are five themes in this budget which I would like to describe to you. First, it provides for the completion of the ongoing program in a timely manner. Second, it allows us to move boldly in a key area of space science, to ensure that our world leadership is preserved in the future. Third, it provides for new flight opportunities in the near term for small missions, which are key to the training of the next generation of scientists and engineers. Fourth, the budget allows us to move aggressively, but sensibly, to build science instruments for the Space Station and its platforms. And fifth, the budget makes key augmentations to the Research and Analysis base, which is the foundation to our program. These five themes are important to pursue not only in FY 1989, but also will be essential elements in budgets that I will present to you in subsequent fiscal years. Permit me to describe the FY 1989 budget requests for each on these themes in turn.

The budget includes sufficient resources to keep each of the major flight programs on schedule for launch in its manifested slot on the Shuttle or an ELV. Indeed, the long hiatus in space science launches is about to be over. In 1989, we expect to launch the Cosmic Background Explorer, the Magellan mission to Venus, the Hubble Space Telescope, the Astro Spacelab mission, and the Galileo mission to Jupiter. In August of 1989, we will also have the Voyager encounter with Neptune, for a truly exciting year in space science.

Second, our FY 1989 budget request makes a bold statement that the United States will be a world leader in space science. We have requested a new start for the Advanced X-Ray Astrophysics Facility—AXAF.

Our Nation is poised for an accomplishment unique in the history of humankind—to observe the physical universe with unprecedented completeness and resolution. We have the demonstrated capability to construct high technology orbiting telescopes that can observe the universe in all forms of electromagnetic radiation, and we have the unique capability with the Shuttle, and eventually the Space Station, to maintain these telescopes on orbit.

The key to realizing this ambition is the start in FY 1989 of AXAF—a telescope facility designed to observe the universe in the x-ray region of the electromagnetic spectrum. AXAF is 100 times more sensitive and has 1000 times more capability for spectroscopy than any previous or planned x-ray mission. In this era in which United States leadership in space is being challenged, a new start for AXAF will provide a bold statement that in the premiere scientific discipline of astrophysics, we will be second to none.

AXAF is to fly in concert with the Hubble Space Telescope, which will observe the universe in visible and ultraviolet radiation, and with the Gamma Ray Observatory, which will observe in gamma rays. These Great Observatories, operating together, will provide a complete physical picture of the universe's most enigmatic objects and will observe the whole range of phenomena in the universe, from the most tranquil to the most violent.

AXAF will also provide a scientific opportunity that is unlikely to be repeated for many generations. The closest supernova to occur near Earth since the invention of the telescope, 400 years ago, was seen last year and can be studied by AXAF provided that it is launched by 1995, before the x-rays fade. Supernovae are responsible for the origin of all of the heavier elements in the universe, including those essential for life.

The funding request for AXAF is $27 million in FY 1989. The runout cost for the development program is about $1.5 billion spread over seven years. This runout fits, year by year, within a budget for the Office of Space Science and Applications which is constant in real year dollars, in FY 1989 and beyond.

It is important to note that all of the major flight projects in the ongoing program will be launched by 1993. It takes four to six years to develop a flight project. Thus, what we start in FY 1989 will be the next generation of flight projects. We have a hiatus in space science launches today because of the Challenger tragedy. Let us not create another hiatus in the mid-1990's by failing to start major flight projects now.

It is important also to prepare ourselves for the major initiatives of the future. Our FY 1989 budget request supports Advanced Technology Development in Solar System Exploration to prepare the Mariner Mark 2 program to explore the outer solar system, another area of traditional United States leadership which we must maintain. This program will begin with missions to rendezvous with a comet and to probe the atmosphere of Saturn's moon Titan. These missions are currently being studied for launches in the mid-1990's. Further, we will also support the Office of Exploration studies of new agency initiatives, such as a Mars Rover Sample Return mission, as a precursor to human exploration of Mars.

In support of the third theme, our Explorer program will provide near term flight opportunities. There is a clear and present need to stimulate the research community, particularly at universities, with exciting new research opportunities, which will attract new scientists and engineers into space science. Historically, the Explorer program has been one of the means by which we have provided such research opportunities, through frequent launches of focused science missions. Accordingly, we are proposing an Explorer program that allows for more small missions, which can be launched on Scout-class ELV's. Such missions are sufficiently small so that they can be built and launched within three years, yet they are sufficiently capable to accomplish first-class science objectives in astronomy, space physics, and upper atmospheric physics. We anticipate releasing shortly an Announcement of Opportunity to select these missions, and we expect that this opportunity will be welcomed by the science community as yet another indication that the space program is moving forward again.

The fourth theme in our budget proposal concerns Space Station. It is time to begin to develop aggressively the principal areas of space science and applications that will take advantage of the unique opportunities that Space Station will provide us. There are four such areas: microgravity science, life science, attached payloads, and earth science from the Polar Platform. Each area has a separate strategy.

The Space Station will provide us with a laboratory in which, with continual human interaction, we can conduct a broad range of microgravity experiments, in material science, in fluid transport, and in biotechnology. These experiments will advance our knowledge of basic physics, chemistry, and biology, and will have direct applications to improving our understanding of processes which occur on the Earth and in space. To use the Space Station as a laboratory, we need to develop six facilities: (1) a Modular Multizone Furnace Facility, (2) a Modular Combustion Facility, (3) a Fluid Physics/Dynamics Facility, (4) a Modular Containerless Processing Facility, (5) an Advanced Protein Crystal Growth Facility, and (6) a Biotechnology Facility. We further need to fly these facilities in advance of the Space Station, both to test and to perfect the design of the facilities, and to provide new research results in the important field of microgravity science. The budget initiative for microgravity science proposed here provides for the full development of all six facilities required for Space Station, and allows for their test flight on a Spacelab and/or Commercially Developed Space Facility. The program leads to the full instrumentation of Space Station for Microgravity science by the time of Man Tended Capability.

Life sciences research is also an important activity that we will conduct on Space Station. Here, however, we have ongoing studies on precisely how we will accommodate the life science research on Space Station. Accordingly, we are proposing this year to begin development of only one of the facilities that we are certain that we will require on the Station--the 1.8m centrifuge, which is essential to any biological research in space. As with the microgravity facilities, the centrifuge will be flown and tested on a Spacelab and/or Commercially Developed Space Facility, and then transitioned to Space Station. The remaining budget request is for planning funds, which will allow us to complete our studies of the optimum means to accommodate the life science facilities on Space Station. We anticipate a FY 1990 budget initiative to develop these facilities.

The Space Station also provides attached payload opportunities, which can be taken advantage of by a broad range of science and applications disciplines. Accordingly, we are requesting, in the FY 1989 budget, funds for an attached payload initiative. Our strategy here is to begin with attached payloads that are not overly demanding on the environment and pointing capabilities of the Space Station. As we learn to use the Station and its full capabilities, we will evolve into more sophisticated attached payloads.

The Polar Platform of Space Station provides us with the opportunity to make detailed observations of the Earth, how it is evolving on a global scale, and how we as humans are influencing that evolution. In January, we released an Announcement of Opportunity, jointly with the Europeans and the Japanese, to select investigations for the Earth Observing System, or Eos, which is to fly on the Polar Platform. Eos is a candidate new start for FY 1991, and this payload selection is part of our normal process of preparing a mission for new start consideration. Included in our FY 1989 budget request are funds to support the selection and subsequent study of this payload.

The four parts of our Space Station initiative--the development of microgravity facilities, the development of the centrifuge and the planning for other life science facilities, the development of attached payloads, and the selection and study of earth observing instrumentation for the Polar Platform — are a comprehensive plan by the space science and applications program to make full use of the unique opportunities that Space Station will provide to us.

The fifth and final theme concerns the Research and Analysis program, which is the vital underpinning to our program - the base support for a vigorous and productive research community. In FY 1989 we propose to continue our rocket and balloon campaign to understand the recent supernova, in advance of when it can be observed and studied by the Great Observatories; to complete the purchase of a new high flying aircraft; and to provide additional resources to take maximum advantage of the upcoming encounter of the Voyager spacecraft with Neptune. We also plan to begin development of a network of signal processing equipment to be attached to radio astronomy facilities to search for intelligent life in our galaxy, and begin the search in 1992. Detection of life elsewhere in the universe may be the most profound event to occur in human history.

The FY 1989 budget request permits us to complete the ongoing program and to build to the future, with confidence that we are providing this nation with a space science and applications program that is second to none, and that in doing so we, as does the entire civilian space program, are making an essential contribution to the national welfare.

Before I briefly describe the specifics of our FY 1989 Budget Request, I would like to mention just three significant highlights that occurred during the past year - the Supernova, the Antarctic Ozone Hole Investigation, and our participation in the 1987 Soviet COSMOS biosatellite flight. These serve as examples of the return we have realized on our investment in Space Science and Applications.

HIGHLIGHTS

Supernova 1987A

In February 1987, an opportunity to study the most energetic event in the universe occurred when the closest observable supernova in over 400 years was discovered. Located in the Milky Way's nearest neighbor galaxy, the Large Magellanic Cloud, the proximity of this event, known as SN1987A, provides a unique opportunity to probe some of the most fundamental questions about how stars evolve and die. A supernova is the consequence of the collapse and explosion of a star upon exhaustion of its nuclear fuel. The explosion itself is accompanied by a brilliant optical display in which an otherwise inconspicuous star outshines all of the other stars of a galaxy for several months and gradually fades from view over the course of several years. In response to the discovery of this event, the Office of Space Science and Applications (OSSA) has initiated a coordinated program of observations of SN1987A across the electromagnetic spectrum, utilizing existing orbiting satellites (the International Ultraviolet Explorer (IUE) and Solar Maximum Mission (SMM)) and our suborbital program (balloons, sounding rockets, the Kuiper Astrophysical Observatory (KAO)) and the NASA Deep Space Network (DSN). To date, unprecedented new data on this object have been obtained at radio wavelengths using the NASA DSN, in the infrared with the KAO, in the ultraviolet band with IUE,in the x-ray region with a set of sensitive rocket payloads, and in the gamma ray region with a cadre of balloon-borne instruments. These observations will reach a climax in 1988 as the supernova attains maximum gamma ray emission and will continue into 1989 when we expect to begin seeing the remnant, which may be a "pulsar", from the explosion. We are also presently investigating the feasibility of conducting a flight of an ultraviolet/x-ray observatory combining the ASTRO and Shuttle High Energy Astrophysics Laboratory (SHEAL) Broad-Band X-ray Telescope (BBXRT) Spacelab payloads on the orbiter Columbia in late 1989 to investigate the nature of SN1987A over a very wide spectral band with the most powerful instrumentation currently available. The agency's extremely rapid and comprehensive response has been widely acclaimed by the international scientific community.

Antarctic Ozone Research

The depletion of ozone in the austral spring over Antarctica was first reported by the British Antarctic Survey in 1985, who used a ground-based sensor to measure the total ozone column over Halley Bay. This finding was quickly confirmed by data from NASA's Nimbus-7 Total Ozone Mapping

Spectrometer (TOMS), which also showed the spatial extent and temporal (seasonal) evolution of the "ozone hole." In order to investigate the cause of the hole and its implications to the global system, the NASA Upper Atmosphere Research Program (UARP) assembled a team of four research groups to go to the National Science Foundation (NSF) base at McMurdo Station in August-October 1986. The team included researchers from UARP-sponsored university groups and NASA center researchers, and a group from the NOAA Aeronomy Laboratory. The Chemical Manufacturers Association (CMA) co-sponsored the expedition, along with the three U.S. agencies. Among other findings, the expedition found that most of the ozone depletion occurred from 12-20 km, and that there were very low levels of nitrogen dioxide. This disproved one of the theories which had been proposed to explain the phenomenon.

While the data from the 1986 campaign greatly improved our knowledge of the Antarctic stratosphere, it was clear that observations were required from a high altitude aircraft to make in situ measurements at the 18-20 km altitude of the maximum ozone depletion. Although aircraft campaigns normally require 3-5 years of instrument development and planning, it was possible to mount the Airborne Antarctic Ozone Experiment in August 1987 because the NASA ER-2 had been earlier equipped with instrumentation for the NASA Stratosphere Troposphere Exchange Project (STEP). The culmination of that project was a deployment to Australia in January 1987, with instruments ideally suited for studying the chemical and physical composition of the stratosphere. The key measurement to be added to the STEP complement was a modification of a balloon-borne chlorine monoxide (ClO) instrument which had originally been developed in the UARP. In addition to the ER-2, the remote sensing laboratory aboard the NASA DC-8 was used. The Airborne Antarctic Ozone Experiment was organized and primarily funded by NASA, with a substantial contribution from NOAA and essential involvement by NSF, the CMA, and meteorological organizations overseas. The cooperation of the Chilean government was extremely helpful in providing the mission base in Punta Arenas, Chile. Tentative findings of the expedition include strong indications of both meteorological (dynamical) and chemical influences, and that chlorine chemistry plays an important role in the formation of the ozone hole. The question of implications to ozone outside of the Antarctic region remains open at this time, and is the subject of continuing investigation. The NASA UARP has also played a major role in furnishing scientific advice on the global ozone depletion issue to the U.S. government as well as the UNEP international process which, at a historic meeting in Montreal in September, formulated a Protocol to Protect the Stratospheric Ozone Layer. In this pact, 24 nations agreed to limit the emissions into the atmosphere of ozone-destroying chlorofluorocarbons.

COSMOS Biosatellite Flight

The NASA Life Sciences division participated in the 1987 Soviet COSMOS biosatellite flight, the sixth joint biosatellite mission since 1975. Twenty-six U.S. investigators conducted experiments dealing with a number of biomedical topics ranging from calcium metabolism and radiation dosimetry to tissue biochemistry and histology. Although data analysis is still in process, researchers are already seeing important results regarding changes in bone marrow, hormone production and, muscle and bone conditioning as a consequence of exposure to low gravity. The ongoing cooperative program in

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Space Biology and Medicine offers a unique flight opportunity to U.S. scientists. Plans are underway for U.S. participation in the upcoming 1989 Biosatellite flight. In addition, U.S. scientists have continued to work with Soviet scientists to understand the extent and implications of bone loss during long duration space flight.

BUDGET SUMMARY

I would like now to briefly describe the FY 1989 budget request for Space Science and Applications. The detailed budget, with narratives, has been submitted under separate cover. A summary is provided on charts 1 and 2. The total FY 1989 request for Research and Development for the Office of Space Science and Applications is $1859.6 million. This request will provide the critical support needed to continue our recovery from the Challenger accident, and prepare us for the future. I would like to highlight some of the more significant elements of the budget request.

We request $791.6 million for Physics and Astronomy. This will provide for continued development for the Hubble Space Telescope, to be launched in 1989 and the Gamma Ray Observatory, to be launched in 1990. It also requests an augmentation for the Explorer development line, which will provide new opportunities in the near term for Scout and Delta class science payloads. This budget line also includes Global Geospace Science, a program managed in our Space Physics Division. The Space Physics research activities were previously carried in the Environmental Observations line of Space Applications. Of particular note in this budget is the new start funding requested for the Advanced X-Ray Astrophysics Facility (AXAF). AXAF will provide a view of unprecedented sensitivity, spatial resolution, and spectral resolution of the x-ray universe. With this initiative, AXAF will be ready for a 1995 Space Shuttle launch.

We request $404.0 million for Planetary Exploration. This will provide the funding required to continue the steady recovery process from the Challenger accident and to design an active and exciting planetary exploration program for the future. The funding request will support continued development of the Galileo mission to Jupiter and the Magellan mission to Venus, both scheduled for launch in 1989. These major events, coupled with the Voyager 2 encounter with Neptune in August will clearly make 1989 a year of outstanding achievement in the Planetary Exploration Program. The FY 1989 request will also support continued development of the joint NASA-European Space Agency Ulysses mission to investigate the Sun at high solar latitudes. Ulysses is scheduled to be launched in 1990. The FY 1989 request will also support continued development of the Mars Observer, scheduled for a 1992 launch, and some advanced technology development funding for potential future Mariner missions, the Comet Rendezvous Asteroid Flyby to rendezvous with a comet and the Cassini mission to probe the atmosphere of Saturn's moon, Titan.

We request $101.7 million for Life Sciences. This level of funding will continue support for our logical build-up to the Space Station era. Of major significance is an initiative for the development of a 1.8 meter flight centrifuge facility that will provide access to the full range of gravity under controlled conditions. This will make a major contribution to our ability to prepare for, and exploit the unique capabilities of the Spacelab, the Commercially Developed Space Facility, and Space Station.

In the Space Applications budget, we are requesting $82.1 million for Solid Earth Observations, and $368.3 million for Environmental Observations. This funding level will continue to support the strong progress we have made in studying the individual components of the Earth, including the interior, crust, biosphere, oceans, ice cover, atmosphere, and ionosphere. It will also allow us to undertake important steps toward developing an understanding of the Earth system as a whole. The budget will support a wide-ranging research and analysis program in upper atmosphere, oceanic processes and atmospheric dynamics. Space Physics Research and Analysis, previously supported in this line, now appears under the Physics and Astronomy line. The request includes $103.9 million to continue development of the Upper Atmosphere Research Satellite program, which is directly responsive to NASA's mandate to develop and implement a comprehensive program of research, technology and monitoring of atmospheric phenomena. Also included is funding for the cooperative U.S./French Ocean Topography Experiment (TOPEX), which will provide the measurement capability needed to determine the circulation of the global oceans and the influence on global climate.

We request $73.4 million for Microgravity Science and Applications. This request will allow us to continue work on new facility class hardware that will eventually be used on Space Station. This funding level will support the orderly evolution from the Shuttle Spacelab to the Space Station.

We are requesting $16.2 million for Space Communications and $22.3 million for Information Systems. In Space Communications, we will continue to support critical effort in the Satellite Aided Search and Rescue (SARSAT) Program, radio Science and Support Studies, Communications Data Analysis and Advanced Communications Research. In Information Systems, we will continue our multi-disciplinary activities to improve our capabilities to acquire and distribute space science data. No funding is requested in FY 1989 for the Advanced Communications Technology Satellite (ACTS) Program, consistent with the position of the Administration, to avoid possible competition with the private sector and to minimize government subsidies for activities more appropriately and effectively undertaken by the private sector.

I believe that this budget request is consistent with the requirements for continued U.S. leadership in space science and applications. As mentioned at the outset, this budget request supports a vigorous and forward-looking Space Science and Applications program. It will continue the critical support needed to carry out the ongoing program, prepare us for an orderly transition to the Space Station, and establish the strong planning base needed for the program of the future. Thank you.

OFFICE OF SPACE SCIENCE AND APPLICATIONS
FY 1989 BUDGET REQUEST
(DOLLARS IN MILLIONS)

	FY 1987 BUDGET	FY 1988 BUDGET	FY 1989 REQUEST
PHYSICS AND ASTRONOMY TOTAL	564.0	610.8	791.6
HUBBLE SPACE TELESCOPE DEVELOPMENT	98.0	93.1	102.2
GAMMA RAY OBSERVATORY DEVELOPMENT	50.6	53.4	41.9
GLOBAL GEOSPACE SCIENCE		20.0	101.4
ADVANCED X RAY ASTROPHYSICS FACILITY			27.0
SPACELAB PAYLOAD DEVELOPMENT AND MISSION MANAGEMENT	72.8	54.2	61.5
PAYLOAD AND INSTRUMENT DEVELOPMENT		43.7	77.1
SPACE STATION PLANNING/ATTACHED PAYLOADS	15.5	18.9	8.0
EXPLORER DEVELOPMENT	55.7	67.9	82.1
MISSION OPERATIONS AND DATA ANALYSIS	131.0	132.0	156.2
RESEARCH AND ANALYSIS	53.4	82.9	89.1
SUBORBITAL PROGRAMS	79.1	44.7	45.1
PLANETARY EXPLORATION TOTAL	359.2	329.2	404.0
GALILEO DEVELOPMENT	71.2	51.9	61.3
ULYSSES DEVELOPMENT	10.3	7.8	10.3
MAGELLAN DEVELOPMENT	97.3	73.0	33.9
MARS OBSERVER DEVELOPMENT	36.8	53.9	102.2
MISSION OPERATIONS AND DATA ANALYSIS	75.1	74.7	112.7
RESEARCH AND ANALYSIS	68.5	67.9	83.6
LIFE SCIENCES - TOTAL	71.8	68.5	101.7
FLIGHT EXPERIMENTS	30.0	30.9	54.5
RESEARCH AND ANALYSIS	41.8	38.6	47.2
SPACE APPLICATIONS			
SOLID EARTH OBSERVATIONS - TOTAL	72.4	74.3	82.1
SHUTTLE PAYLOADS	21.4	20.8	26.3
GEODYNAMICS	31.6	32.4	33.9
RESEARCH AND ANALYSIS	19.4	21.1	22.9
ENVIRONMENTAL OBSERVATIONS - TOTAL	318.3	313.5	368.3
INTERDISCIPLINARY RESEARCH AND ANALYSIS	1.1	1.1	1.2
UPPER ATMOSPHERE RESEARCH AND ANALYSIS	32.7	32.7	34.0
OCEANIC PROCESSES RESEARCH AND ANALYSIS	18.0	20.2	21.8
ATMOSPHERIC DYNAMICS/RADIATION RESEARCH AND ANALYSIS	31.3	31.4	32.8
SPACE PHYSICS RESEARCH AND ANALYSIS	20.8		
PAYLOAD AND INSTRUMENT DEVELOPMENT	9.7	4.1	19.7
TETHER PAYLOADS	5.5		
MISSION OPERATIONS AND DATA ANALYSIS	33.6	14.8	18.5
UPPER ATMOSPHERE RESEARCH SATELLITE	113.8	89.6	103.9
SCATTEROMETER	32.9	22.7	15.8
OCEAN TOPOGRAPHY EXPERIMENT	18.9	75.0	97.8
AIRBORNE SCIENCE AND APPLICATIONS		21.9	23.0
MATERIALS PROCESSING IN SPACE TOTAL	47.3	62.7	73.4
RESEARCH AND ANALYSIS	13.9	12.9	13.6
MATERIALS EXPERIMENT OPERATIONS	33.4	49.8	59.8
SPACE COMMUNICATIONS TOTAL	103.4	94.9	16.2
SEARCH AND RESCUE TRANSITION	1.4	1.3	1.3
RESEARCH AND ANALYSIS	17.4	18.0	14.9
ACTS DEVELOPMENT	84.6	75.6	
INFORMATION SYSTEMS	21.2	20.9	22.3
TOTAL OFFICE OF SPACE SCIENCE AND APPLICATIONS	1547.6	1575.8	1859.6

Senator KERRY. Mary, why don't you take off, and then we will ask questions. I am going to ask some of you as you go along and then we will come back to Dr. Fisk.

STATEMENT OF DR. MARY L. CLEAVE, MISSION SPECIALIST, ASTRONAUT OFFICE, LYNDON B. JOHNSON SPACE CENTER

Dr. CLEAVE. Senator Kerry, Dr. Fisk, and everybody here today:

It is nice to talk to you. I am going to talk about a little more practical things, looking at our planet from orbit, hopefully demonstrate to you what—I am going to show you some hand-held photography from

space. When we go fly in the shuttle or any other man-tended platform we are on, they give us little hand-held cameras. We have 70 millimeter Hasseblads and 35 millimeter Nikons and a four by five inch Lenhoff.

Senator KERRY. We want you to take a Polaroid in the future.

Dr. CLEAVE. The advantage of having a man in the look up there is when you get satellite data you get a lot of very good data and you can point latitude, longitude, and that kind of stuff, except that there is no filter there and you can very, very rapidly get drowned in data.

And so we work with experts like oceonographers and geologists. They train us to look for certain things. We keep our eyes out and take a picture, because we have a brain and that is a big filter.

And so if we could start with the first slide.

[Slides shown]

Dr. CLEAVE. When we launched in November of 1985, we were very lucky. We launched on a full moon and we had a night launch. It was really interesting flying with a full moon. It does affect your operations, because you do not get to think about dark side, just like you would in astronomy with a full moon on the planet.

But this shows you there are really some pretty esthetics out of this, and not all of the pictures that we take are just all science. We take some pretty pictures, too.

Senator KERRY. Mary, can you describe for us in terms of pictures you are taking what the scientific objective was?

Dr. CLEAVE. We had a number of them.

Senator KERRY. Can you just quickly run through them.

Dr. CLEAVE. For weather, we were taking pictures of weather phenomenon, high resolution pictures that they can compare against the satellite data. For geologists, we were taking pictures of different geological formations. For oceonographers, we were taking pictures of different oceanographic events.

And just in general, I was taking pictures of any kind of land use planning changes I could see on the planet and pollution effects.

This is a picture here—and can you focus this, because I do not think I can focus it from down here. These are thunderstorms over Mexico. Thunderstorms are of big interest to aviation because they are very disruptive. When you get an aviation thunderstorm located over any kind of airport, it really wreaks havoc with everything and also it really impinges how we can launch and land spacecraft.

These are about—the big one is topping about 70,000 feet. We take these pictures and then the weather guys compare it to their weather satellite data. It helps them because it is high resolution. We also can track lightning phenomenon.

This is out of focus and it is probably a good demonstration of what these weather phenomenon sort of look like when you are looking at it from a weather satellite with the resolution of data they have. And that is why it helps them for us to take high resolution pictures.

Can we focus this, please?

Now that we have had our little demonstration, thanks.

This is a cyclone over the Pacific. You can see the eye of the cyclone in the center, the abrupt overshoot and thunderstorms in the middle. That is what creates a lot of damage with cyclones and the tornadoes they spawn towards the eye.

The nice thing of being on orbit and trying to see things and take pictures of them and track things is the fact that when you are in a space ship your orbit precesses and you will move back. And so if you see something, you wait for the next orbit and you get ready. And all of a sudden you can look down and you are looking right down the eye of the storm, because your orbit has precessed over to where that point on the planet is.

So this is the same cyclone we just saw, but looking right down the eye.

And you can see the ocean underneath. And again, what the weathermen are interested in is the structure of the other overshooting thunderstorms around the eye.

Senator KERRY. What would the tops be on that?

Dr. CLEAVE. They are at least 70, but probably higher than that even. I am not really sure.

Another thing we like to track from orbit are different bodies of water. We see changes in water levels, both increasing and decreasing. This is—we have been taking pictures regularly of Lake Chad since Skylab and all the way through. Even Gemini took some pictures of Lake Chad.

This is a current picture of Lake Chad. You can see that the reflection towards the bottom, the sort of silvery part in the lower part of the slide here. And I have a pointer, so I can point. Right in there is the water that is left. This used to be the whole lakebed.

Even during Gemini there was water up in these regions. And now you can see sand dunes have taken over.

You can do some computer work with this and actually track changes in water level.

Another lake that is of particular interest to me because I lived in Utah for so long is the Great Salt Lake, which has also been having changes in lake level, but the other way. They have been having trouble with the water going up and flooding things.

This picture was taken about, oh, five years ago of the Great Salt Lake. And look at this area right in here. You will see a picture that was taken two years later.

Right down in that area, you can see that the lake level has gone up. You can also see differentiation in water quality. That is a great big rail bed and you can see that it actually divides the lake in two, and there is differences in salinity in the water between the top and the bottom part.

Senator KERRY. Mary, would that kind of resolution show up from a satellite photograph?

Dr. CLEAVE. Yes, if you know what to look for. But if you do not know what to look for, you have trouble picking it out of the data. But Landsat has very high resolution.

Senator KERRY. In the debate between manned and unmanned, maybe I should say personned and unpersonned——

Dr. CLEAVE. That is fine.

Senator KERRY. Is there something you can share with us about why the manned vehicle is one which results in additional information such as you have just described?

Dr. CLEAVE. I think it is mainly because in science you have a plan and you try to learn specific things, but so much of what you learn in the laboratory happens accidentally just by using something that you did not expect and pursuing that.

And that is true also in space as a laboratory, too, that there is a lot of breakthroughs to be made just by having enough sense to look at things that happened the way you did not expect them or do not look the way that you think they should.

People always ask if you can see manmade phenomenon from space, and here you can see the Suez Canal. It is very clear coming down. The Nile River delta, it looks very peaceful and calm. The Middle East looks really peaceful and calm from space.

Not to slight anyone, we were really lucky because we got to fly with a Mexican national, Rudolfo Neri Vella, and so we were really looking forward to having very little cloudiness. And one of the problems is that satellite sensors cannot detect what a man can detect and not take the data is, if you are trying to take pictures of a land mass then cloud cover is going to get in the way, okay.

So here we have the Panama Canal Zone, which is usually cloudy. And if you squint your eyes, you can see the green strips. That is the Panama Canal Zone.

Different land use strategies in different countries actually do make you be able to pick out countries is if they were a political map. This is something I did not really expect that I found to be really distressing, because especially in Africa you can pick out different countries based upon different land use management schemes that they are employing.

Here is a great big reservoir that, they use that to pump water from that reservoir to pump up the locks. The canal goes right down there.

Panama also looks very peaceful from space.

Now, when you look into Brazil, going a little farther south, you can see all of this grid line area. This is the Amazon basin. Every time we fly we take pictures of the Amazon basin, and the amount of agricultural development there is really astounding. You can see how large an area here is being developed.

These are all teeny-weeny little patchwork quilts of little farms. And you can also see a lot of burning in that area, where they burn the forests off.

Deforestation like you saw in the Amazon can have an impact on streams. This is Madagascar and this is the Betsy Botha River. They are doing a lot of logging in Madagascar, hardwood forest logging. And

every time we fly we take pictures of this delta, and you can see how it is filling in.

This whole basin right here is really just filling in from sedimentation, the dirt coming off after they have logged these forests in Madagascar. And that is visibly noticeable.

When you fly over the Midwest and you look down, or Texas—I am living in Texas now—and you see these great big irrigation, circular irrigation patches. Well, this is what they look like from space. They are just a little smaller.

These happen to be alfalfa that is being grown in Saudi Arabia, and so this is probably pretty expensive alfalfa right here. And you see what happens when they stop pumping the water. The sand just sort of blows back in and takes it over again. That is pretty old water they are mining right there.

This is back in South America. We work with volcanologists. That is one person I did not mention before, volcanologists. A lot of times, you know, when you are trying to do a model of the upper atmosphere and you have volcanoes going off and it is adding a lot of particulate matter to the upper atmosphere, and you have people trying to do models and do a mass balance. And if you have a volcano go off and nobody knows about it, it really wreaks havoc with your data.

So they tell us, take pictures of volcanoes if you see them erupting. And we have taken pictures, I think, of three or four volcanoes that were not recorded while they were erupting.

Here is a volcano here. You see, in an area like this in South America it is very easy to have a volcanic eruption without anybody even knowing it, because there is nobody around there.

Land use. One thing that struck me, this is Mount Kilimanjaro, another volcano but not an active one. You can see from space exactly where that national park stops and starts, and it is really amazing. You can make a great tour guide to all the national parks on this planet, because you can pick them out from space because of different land use policies. They are fenced and they really look different.

Can we focus this a little bit?

I want you to look for these little dots right here. We take a lot of pictures. You can see ocean currents right here. What I want you to see are all these ships. There are about 17 of them. You can see ships real easy from space, even if they are parked. These guys are parked.

Here is the coast of Bahrain. I do not think these guys are parked here any more, but there were about 17 supertankers. After the price of oil went down, they just had them mothballed right there.

This is something that I really appreciated, but that not too many people appreciate. This is in the Coral Sea and this is a great big huge fire plankton bloom, about—it looked like it was about 125 miles across. This is probably where the whales go and feed.

Senator KERRY. Mary, were you able—could you make any determinations with respect to acid rain visually?

Dr. CLEAVE. You can see effects of acid rain vividly around smelters, where the vegetation is lower. And if you take infrared pictures, you can quantify that.

Coral reefs, and this is the Devil's Tongue in the Caribbean. We take a lot of pictures of them. Right now there is an issue of them turning white for some unknown reason and dying off, and so we have been tracking them on a regular basis.

Oceanographers. These lines right here you see are great big internal waves. They are a huge phenomenon. There is probably five kilometers in between one peak to another.

They are not very high on the surface, but they are very, very deep, and they have a lot of energy. And for a while there were oil rigs getting knocked over and they could not figure out what it was. They had a theory that they had these big packets of standing waves, but nobody had ever seen them.

And the first time they actually got to see these waves was when Vance Brand took pictures of them, because he was looking for them. Because of the perspective you are looking at from, you can actually see them.

Senator KERRY. How high was that wave?

Dr. CLEAVE. Do you mean high off the surface of the ocean? Maybe just a foot. You would not really notice them. But they are very, very deep, and they pack a lot of energy.

This is the mouth of the Ganges River. This is the mangrove swamp. We took a lot of pictures of India because we had a good daylight pass, and then we ended up donating a lot of pictures to the Indian government and I got to go to India last fall and talk to a bunch of folks.

That is one great thing about the space program. We tend to cooperate a lot in various areas, and everybody is sort of rooting on the same side when you talk about one little planet.

You can see the sedimentation here coming out of the mouth of this river. This also, by the way, is a national park. I found this out. Guides do not like to go in there and work because there are so many tigers they do not come out. And so they like to do aerial studies in there.

This is an infrared film, the same thing. If you use different kinds of films you get different information. With infrared film you get chlorophyl coming out as red. Sedimentation, that cuts off at different layers under the water and so you get different sedimentation information.

And we compare the two. We had two different cameras, we took pictures. I took one and a marine took the other one. His was better than mine, though. It is really depressing.

This is the mouth of the Mississippi River, which you can see looks really geologically—it should be coming up in level, but because of what they think is wave erosion from boats and stuff, it is actually sinking. You can see the Corps of Engineers has been working real hard to keep that open.

This is a city in China, another IR film. And you see these little—it took a long time for us to find out what these little structures were. We were looking down and asking a lot of questions, and finally we found out these were all fish traps.

That way they do not have to refrigerate the fish. The fishermen go out, they bring them in and store them in these fish traps, store them until they are ready to use them.

Geologists, we work with them a lot. And the Himalayas do not look so big and Mount Everest does not look so big in this picture. And this picture is the Indian plain. But if you look at it—and all this crumpled up region, they say that the subcontinent of India is smashing into the bottom of Asia, and when you look at the planet from space you can really see plate tectonics, and it makes a lot of sense and it really looks like India is really hitting Asia and it is just crumping up like tin foil right in there.

This is what a sunset looks like on orbit. When you live on this planet, you get a notion about what daylight and night should be, only sort of budged by Daylight Savings Time. But on orbit where we were, it was daylight—one day took an hour and a half lighting wise, so every about 45 minutes we had a sunrise or a sunset, and they were really spectacular.

Right in there, you can see the various layers of the atmosphere. And if this slide was in focus a little better, you could see some clouds right in there.

Well, we did not take a picture like this. You have to get far enough away. This is from the Apollo program. But I think this one picture really changed me a lot. What one picture can do to somebody, it made me become really interested in the environment.

And after going around, I think, talking to people all over the planet, I think it had made people understand that we all live in one little planet.

Thanks.

Senator KERRY. Mary, thank you very much.

I was going to ask you, and I think you partly answered it in your last slide, but I might still ask you, what to you would be the most important lesson you bring back from your experiences and experience in space as an astronaut? Could you highlight something that you think is the most important thing that the committee, the Congress, and the audience ought to think about?

Dr. CLEAVE. I think it is probably a group of people working together in a very confined space that, if trained properly, can get a lot of work done, be prepared to do things even that they were not necessarily planning to do, and therefore optimize the amount of activity going on.

It is very, very hard to automate processes that you do not understand, and that is basically what we are asking a lot of people to do, and I think it is almost impossible to do that.

Senator KERRY. What do you think about the importance of the international cooperation in the space effort?

Dr. CLEAVE. I think flying with Rudolfo was an excellent experience, and it is a very, very important part of the space program, international cooperation, not just on orbit, but also in the sharing of data and approaches to different experiments and setting them up together and working them together.

Senator KERRY. Dr. Fisk, we had a budget six years ago, I think it was 1980, in the civilian space program of about $3.8 billion. At the end of last year it was about $9.1 billion or so, and I think we are talking $11 billion this year.

The DOD space program was at about $4.8 billion in the same time period and it is now at about $20 billion, and about to be $22 billion.

Would you discuss that divergence and what it means and perhaps why that has happened?

Dr. FISK. Well, let me take this a couple of ways here. There has been, of course, growth in the military space budget. Some of that is simply the recognition of the increasing importance of space in all dimensions, including in the military.

It is true that the NASA budget—I think you always have to ask yourself that question in the context of real year dollars or constant year dollars, as opposed to real year dollars, when you say what was the space budget a few years ago.

You say, well, how much did those dollars buy at that time? I looked back not so long ago at what the space science budget looked like a few years ago, and I was intrigued to learn that if you converted that budget into today's dollars that when you got back to 1974 we were spending over $2 billion in fiscal year 1988 dollars, current year dollars equivalent, on space science in the United States.

If you go back to 1965, which was the height of the Apollo program, we were spending somewhere around $2.3 billion or $2.4 billion, which is substantially larger than the amount that we are asking for today. Now, at the very same time that the budgets have really been decreasing with time in terms of their ability to buy things, space has been opening up into many different fields.

In the 1960's, space science was restricted to more or less space plasma physics, a little earth observing, and a little bit of the early days of astronomy. Well, now we are building great observatories for astronomy. We are doing microgravity science in space, we are doing life science in space.

We have all the new dimensions of earth science. And so we are trying to do a lot more in space with in fact fewer resources than we devoted to it as much as 10 to 20 years ago.

Senator KERRY. Is that because of budget constraints or administrative neglect, a lack of political leadership, or a combination thereof? What is the fundamental reason that we have suddenly taken the lead and dissipated it?

Dr. FISK. Well, it is an interesting social-political question, I guess. At the end of the Apollo era, which really ended in the early seventies, we had enjoyed a tremendous success. We had gone to the moon, we had been there.

We beat the Russkies, if that is what the game was. And then the national will got diverted. We were worried about Vietnam and we were worried about many other things, and the space program was allowed to sort of languish. And that has now run through several Administrations. It is not an issue for the Republicans or an issue for the Democrats.

But we allowed the space program to languish. And I think then when the Challenger accident occurred, there was a national awakening. We said, what happened here, how did this all happen?

And at exactly the same time, the Soviets were in the process of opening up their space program to the world. They were basically making space an instrument of foreign policy, and they were opening up their program and that called us into question as to what we were doing with our space program.

I think that is where we are today, with the recognition that the lead that we had was allowed to erode and now we have to ask ourselves, where are we going in the future.

Senator KERRY. If you were sitting in a room with the President of the United States and the key committee chairmen for the appropriate committees and they said to you, "Dr. Fisk, convince us why we should be willing to give you the money," what would you say to them, in a short quick—how would you convince them?

Dr. FISK. Well, I am not sure how articulate I would be, but what I would try and do is point out to the President of the United States and to the leadership of the Congress and whoever it is that is making these decisions that, as elected officials, they have an obligation to not only worry about the near-term problems that the country faces, but its long term future.

We really, hopefully, elect our Presidents and our leaders in Congress to be visionaries, to ask themselves, where should the country be 50 years from now? Where should the country be 100 years from now? And I think if you step back and try and put it on that sort of a time scale, the one thing you rapidly realize is that space will be increasingly important.

If you said to yourself in 1910, was it important for this nation to be involved in aviation, well, some visionary hopefully would have said yes, because 50 years later the country that is in control of a major aviation industry and so on is in fact a world leader.

I have no difficulty predicting that 50 years from now space will be ever more important than it is today, and so then the question arises, is this Administration, is the Congress, going to preserve that U.S. position of leadership in space for the future or not?

Is it going to take the long term vision or the short term vision? If it takes the long term vision, then, however painful it is, however much we need to be concerned about deficits and tax rates and all those things, the investment today is essential, so that 25 years and 50 years from now future generations of Americans can look back and say they made some wise decisions.

Senator KERRY. I get the soft ball of the year award.

We had the Paine Commission report, we have the Dr. Sally Ride report and other exciting concepts that have tried to articulate a program for space. What does it take now for us to initiate these bold initiatives, apart from the leadership issue you talked about?

What do we have to do to respond to those?

Dr. FISK. Well, I think there are three things. The first is a leadership issue, and it is national will as embodied in Presidential and Congressional leadership. The second thing that you need is that commitment, that leadership, needs to translate into some sort of a stable funding base in order to pursue it.

Whenever you embark on one of these projects, you need to know that you are in fact going to pay. It is going to cost you money in the future and you need to commit to that.

But I think probably one thing that your question focuses on most is that in fact you need a stable, healthy space program underneath it. That is, you need to be concerned—these major initiatives involve more than just saying, we have a goal, we are going to go to Mars or something like that.

They require a technological base on which to do it. They require scientists and engineers that are capable of executing it. That means appropriately trained manpower in the NASA centers and universities that NASA depends on.

And so the underlying infrastructure needs to be healthy and needs to be capable of executing this before we go forth.

Senator KERRY. What are some of the candidate missions that you are looking at within NASA and within the office of space exploration with respect to the immediate future?

Dr. FISK. There are several here. Basically just to remind people that in the President's recent policy on space, one of the goals cited for the space program—this was the first time this was ever stated—was to extend human presence into space beyond earth orbit, into the solar system, which for all practical purposes means Mars in the long run.

As my planetary friends have reminded me, the Moon is in Earth orbit, too, and so therefore if we are going beyond Earth orbit the only place to go is Mars.

The embodiment of that in the 1989 budget request is a project called Pathfinder. It is a substantial amount of money to essentially do the technology to make sure that you can in fact execute such a program. Personally, I think it was a smart way to go because, as everyone knows, tomorrow being Super Tuesday, we are at the end of this Administration, and it is not an appropriate call for this President to say what that leadership initiative ought to be.

It is really the next President's job. But what this budget says is, let me do the technology in advance, let me make sure I know that, if he is going to make that decision, he can do it on the basis of sound technology.

Now, as to the specifics, there are three candidates that one considers. There is first of all something called Mission to Planet Earth, which is a concentrated study on the Earth from space, using polar platforms, and geostationary platforms.

Then there are the human exploration initiatives, perhaps to the moon and eventually to Mars. There would be some science precursor missions like Mars Rover Sample Return, that would precede those human missions.

Senator KERRY. As you know, there is a certain amount of debate in both Congress and elsewhere about the space station cost, et cetera. Let me just ask you, are there safeguards that could be implemented to guarantee that the space station is not going to occur at the expense of the space science budget itself?

Dr. FISK. You have history on your side here, at least. Space science and applications has historically had about 20 percent of the NASA budget. In effect, the Congressional committees have even noted that in their last legislation on appropriations.

If history continues—and it is certainly NASA's intention that is an appropriate balance between infrastructure such as space station and shuttle and the users, the scientists. If that sort of balance continues in the future, then the space science program goes along healthily at the same time we are building all of this infrastructure.

People often cite an example and say: Gee, when NASA was building the shuttle, look how bad science was hit; we do not want to repeat that when we do the space station. In fact, science was not hit badly when the shuttle was built. Science still enjoyed about 20 percent of the NASA budget while the shuttle was being built.

There was one big difference at that point, and that was everything had to be launched on the shuttle and therefore science had to wait to do its launching while the shuttle was being developed.

Now NASA has a very healthy, robust launch capability plan—a mixed fleet, expendable launch vehicles along with the shuttle. So long as that continues and science can spend its share of the budget in the most optimum ways, then I think we have a healthy program.

Senator KERRY. In keeping with what you just said or picking up on it, is it essential to the future of the program that you have a robust transportation program that includes both unmanned and manned launch vehicles?

Dr. FISK. It is absolutely essential. In fact, we could not run a healthy competitive science program in this country if that was not the case.

Senator KERRY. How many payloads do you have sitting on the ground now waiting to launch?

Dr. FISK. Over the next four years, the ones that either have been completed and were delayed because of Challenger or the ones that are just coming up for completion, number 20 major missions to launch between now and 1993.

And about half of those are on ELV's.

Senator KERRY. Dependent upon what level of funding to meet that schedule of 1993?

Dr. FISK. There are two parts of the budget. Basically of the growth that occurs in the science budget between 1988 and 1989. About 90 percent of that is simply to keep those space science missions on schedule.

As I mentioned in my remarks, the converse of that is also true. If that growth does not occur, then certain of those missions will be delayed further.

The second part of the budget which is essential is the ELV portion. There is approximately $200 million being requested by NASA in fiscal year 1989 to begin the procurement of the ELV's that are necessary to fly those payloads.

Senator KERRY. Now, in 1989 we will have Ulysses, Galileo, Voyager, Hubble, correct? So 1989 could be assumed to be the year of space science in many respects, is that fair?

Dr. FISK. That is very much a fair statement. It is three years later than the year of space science was intended to be, in 1986. I mean, basically it is a repeat of that.

Senator KERRY. But is it also fair to say that, with the current planning where we are, that we exhaust our current plans by what, 1994 or '5?

Dr. FISK. 1993. The ongoing missions are all cleared, launched through 1993. This is why this regular sequence of new starts for flight programs is very key to us and why we are very concerned that AXAF, which is this year's major new start, is allowed to go forward, because it takes four to six years to build a flight project.

So what you start in 1989 will launch in 1994, 1995, and 1996 and so on. We have this sort of automatic falloff in space science that occurs in 1993 if we do not begin something now.

Senator KERRY. And nothing is in the pipeline?

Dr. FISK. That is correct.

Senator KERRY. A final question if I can, before we move to the next panel, and perhaps a parochial one, but I think one that is important and at the bottom of this hearing. Would you relate to us, if you can, briefly the linkage between the programs you have talked about and Massachusetts and our community, both scientific and technological?

Dr. FISK. Well, Massachusetts is one of those unique places in which you have such a high concentration of educational institutions and a high concentration of high tech industries. Of course, those are the very people that the space program both depends on and which the space program is important to.

We depend very heavily upon the university communities for the new blood, for the new ideas, to actually conduct the research. We depend upon the high tech industries of the United States to execute the space program.

There is some sort of misconception out there when we talk about commercializing the space program, that somehow NASA does this. Most of the research is done and most of the instruments and the payloads that are built and the spacecraft that are built are all built by American industry.

AXAF will be built by American industry. The experiments will be built by the universities. It is NASA's job to put them together into a flight program. So we depend very heavily on the Massachusetts environment because of the unique character of it and its educational industries and its high tech.

Of course, we invest real dollars into the Massachusetts economy. I think if I recall the figure, it is approximately $100 million or in excess of $100 milion a year just in the Boston area alone.

Senator KERRY. I said that was my last question, but I am going to exercise a senatorial prerogative here and filibuster with you.

Dr. FISK. Someone might arrest you.

Senator KERRY. As I said at breakfast, I am here on Senator Byrd's work release program anyway.

Senator KERRY. Just quickly, what does this mean? We are always talking about American competitiveness and the ability of America to compete in this new international marketplace.

Is it fair to say that there is a very direct linkage between our willingness to invest in this arena and our capacity to be able to look towards that kind of engagement in that marketplace in the future?

Dr. FISK. I think that is absolutely true. You can cite specific examples of industries that we have to be sure that we are world leaders in and the space program is a driver for. But I think the proof that I would cite of that is simply the amount of investment that our competitors are prepared to make in this field.

It is not lost on us that the Japanese, the Europeans, and the Russians, are planning and have commitments for substantially greater investments in space. The growth of their investments in space is far greater growth than we anticipate in our program.

Senator KERRY. Let me just add to your previous answer. When you said a little bit over $100 million, I took note because it is not something that you would follow as closely as I do. But it was actually about $400 million last year for some 810 contracts. This year I think we have about 710 contracts already, totaling $385 million.

So we enjoy our relationship with you, and we want it to continue.

Let me thank both of you very, very much. Mary Cleave, I am very jealous of you because you fly T-38's, and I am a pilot and I would love to get my hands on any airplane I can. So one day if you would put me through our paces together, I would be very appreciative.

Thank you both very, very much.

If you would join me in welcoming our second panel: Dr. James J. McCarthy, the Museum of Comparative Zoology, Harvard University; Dr. George Kenney, MIT; Dr. Sean Solomon, Space Science Working Group, the Association of American Universities; Dr. David Akin, Massachusetts Institute of Technology; and Dr. Harvey Tananbaum, Smithsonian Astrophysical Observatory.

Gentlemen, we must ask you—we are going to invoke a Senate custom in the process here. This is the only panel we are going to use this on, so you may feel distinguished. But we are going to try to hold you each to approximately a five minute summary.

Your full testimony will be made a part of the record. And also, I might add, the record will be left open for a period of two weeks so that we might submit some additional questions in writing to any of the panelists, and we would appreciate your responses thereto.

I do not have any particular order. Dr. McCarthy, do you want to lead off? We will just run down the list.

STATEMENT OF DR. JAMES J. McCARTHY, MUSEUM OF COMPARATIVE ZOOLOGY, HARVARD UNIVERSITY

Dr. McCARTHY. I am James McCarthy. Thank you, Senator Kerry, for this opportunity.

Although I am a professor of Harvard University, I am here largely in my capacity as the chairman of an international committee. This is a committee which is named the Special Committee on the International Geosphere- Biosphere Programme.

And the charge of the committee is to design a large scale international program that will address some of the issues that we have heard mentioned earlier in the testimonies of Dr. Fisk and Dr. Cleave.

What I would like to do, Senator Kerry, is just highlight a few points from my testimony, my written testimony, which was submitted to your committee, and then elaborate on one particular point, and that is the use of the remote sensing capability in the sort of study that we are undertaking with the international geosphere-biosphere program.

The first point would be, I think, that, as you are certainly aware today increasingly in the news—and I tried to detail this in my testimony—the geosphere and the biosphere are linked. Biogeochemical cycles and physical processes are coupled to give us the climate of the earth.

The second point would be that the natural processes in these couplings are being perturbed by anthropogenic activities, such as the emission of greenhouse gases.

The third would be that major national and international efforts are now under way to support the science community to address these issues, and there is strong support for this from around the world, including the Soviet Union and the People's Republic of China.

The fourth would be that this is now possible, this sort of study is now possible, and only as a result of the last couple of decades of, A, the accomplishments that have been made in the fields of atmospheric, oceanic, earth, and ecological sciences; B, the dramatic growth in our capability to use computers to process large amounts of data, a point again made by Dr. Mary Cleave, and to model this system; and C, the revolutionary developments in remote sensing for both properties and processes of the earth's system.

The fifth point I would like to make and the final one before I elaborate on the remote sensing issue is that the U.S. science agencies are now poised to advance our understanding of what we are calling global change in the earth system. Several remote sensing missions, as well as land and ocean surface studies, are now in the plans of NASA, NOAA, the National Science Foundation, and the private sector, and

that these plans are critical to not only the United States, but the international scientific efforts to predict how anthropogenic activities will influence the habitability of our planet.

Now, with my testimony I included two color plates that will help to demonstrate how this remote sensing capability is useful to the scientists who are studying these geosphere and biosphere couplings.

Again, as I pointed out in my testimony, ocean biota or the plankton—now, they are too small to be seen with the unaided eye—but because of their green color, mentioned earlier by Dr. Cleave, their chlorophyl, impart color to the water which can be sensed from satellite sensors in space.

[Slide]

Oceanographers on ships collect samples to determine the plankton concentration by analyzing the concentration of this pigment. But with ships crossing the seas at ten knots, it is very difficult to generalize either in time or in space from these shipboard samples. The oceans are simply too vast, and temporal changes on the scale of weather influence the plankton abundance and growth rates.

Now, these imagines, which I have again attached to my testimony, this being the first of the two, are provided by scientists at Goddard Space Flight Center, Dr. Wayne Esaias and Dr. Gene Feldman, and they are a demonstration of the capability which is central to the National Science Foundation and NASA-supported global ocean flux study—one of the large studies that can be seen as a component of the study of global change.

In this first image, what you see is a composite of 18 months of data for the ocean areas, in which the red colors are the high concentrations of plankton, the violet colors are the low concentration. And you see a pattern. Again, over 18 months this is an average. We have two springs and the rest of the year with a single sampling.

You see high concentrations in the North Atlantic and coastal areas, red to green to blue, and low concentrations in the oceanic regions. The black areas here are areas for which there are no data.

If we look at the second image we see—to orient you here, starting on the upper left in January 1979, there is the coast of North America, there is the coast of Africa. We move from January, February, March, April, May and June.

What you see is the development of increasing blue and green in this area, until in April and May you see what is known as the spring bloom in the North Atlantic.

Now, this is an important phenomenon because it is one by which the annual pulse of food into the food web stimulates many of our commercial fisheries. It is also one that is important in the production of organic carbon that goes into the deep sea.

But this is also an example of U.S. leadership in space. This is a capability which was developed in the United States, and currently in the United States there is no instrument flying that will provide these sort of data.

The next opportunity is for 1991 on the Landsat VI, an instrument known as Sea WIFS. And in the near term we have the mission referred to by Dr. Fisk, the Earth Observing System, in which this would be one of the candidate sensors.

On the table in front of me is a stack of documents which have been produced by scientists to make the case for each of the sensors on this particular flight.

Senator KERRY. Can I ask a quick question? What is the reason for the lack of data available in areas at one point in time, and then it is available in others?

Dr. MCCARTHY. Again, these are all of the data for January 1979, February 1979. The black areas, for which no data was collected. There were several competing instruments on this satellite.

In fact, we had no sense at that time that these data would be useful in the way they were. So the satellite was either not turned on here or in some cases not enough passes made to get a cloud-free image.

So I would like to just conclude by again coming back to the point on the Earth Observing System. This is in the 1989 budget for advanced technology development, with a scheduled launch in 1994. And it is essential that we remain faithful to the schedule to retain our position of leadership in this aspect of space science.

It is this capability that Dr. Sally Ride refers to in her report to the Administrator of NASA on leadership and America's future in space under the heading "The Mission to Planet Earth.'

So today we have a timely readiness in the scientific community, the U.S. space science institutions and science funding agencies to tackle a scientific problem of great urgency, the study of global change.

Thank you.

[The statement follows:]

STATEMENT OF JAMES J. McCARTHY, PROFESSOR AND DIRECTOR, MUSEUM OF COMPARATIVE ZOOLOGY AND ASSOCIATE DEAN, HARVARD UNIVERSITY

Thank you Senator Kerry for this opportunity to address the Subcommittee on Science, Technology, and Space. My name is James J. McCarthy, and I am a Professor, the Director of the Musuem of Comparative Zoology, and an Associate Dean at Harvard University.

I also serve as chairman of the International Council of Scientific Unions (ICSU) Special Committee on the International Geosphere-Biosphere Programme (IGBP): A Study of Global Change. In my letter of invitation to this hearing Senators Hollings and Riegle have asked that I "describe the status, goals, and objectives of the International Geosphere-Biosphere Program and how the applications of space-based technologies assist (our) understanding of changes that are occurring in the Earth's unique environment", and how "further initiatives will enhance (our) research and our understanding of global change".

In July 1987 this subcommittee held hearings on Global Environmental Change Research, and you heard from several scientists, including Dr. Frank Press, President of the National Academy of Sciences, and Dr. Lennard Fisk, whom we are hearing from again today. At that time your Subcommittee was presented with a very consistent position regarding the need for research related to global change and the readiness of our science funding agencies to launch major initiatives in this direction. Since then the international planning efforts have begun, additional sectors of the scientific community have joined in supporting this research, some nations are pledging major financial committments to the IGBP, and heads of state are talking of new cooperative agreements that will be essential if we are to implement these plans. However, not all the news has been good. Within the U.S. our research efforts related to the study of global change took a major blow with the end of year deficit reduction measures. The National Science Foundation was particularly hard hit. The future of the LANDSAT capability for land and the complementary capability for ocean biota, SeaWIFS, remain uncertain. And further delays in NASA's schedule would cause concern regarding the ability of the U.S. to keep to its projected 1994 launch of the Earth Observing System, which is essertial for us to remain in the forefront in space science related to the study of global change.

I would like to use this opportunity to review for you some of the underlying rationale for the IGBP, describe the status of the international planning effort, and conclude with comments on the space related component of this research, and particularly the U.S. role.

Natural Change in the Earth System

The history of planet Earth, since its formation more than four billion years ago, is a story of change. The continental masses slowly accrete and reposition as new ocean floor is formed at the mid-ocean spreading centers. Uplifting of continental crust forms mountains, which are constantly being worn down by weathering processes. The solar energy our planet receives varies both as our solar system's star ages and as a function of periodic oscillations in earth-sun orbit.

The evolution of modern life forms over the last three and a half billion years denotes both a change and a cause of change in our planet's environment. The earliest forms of life contributed to the evolution of the basic life support system itself. The chemical composition of the atmosphere is a case in point. It has evolved to its present state, one with about 20% oxygen and only a trace of carbon dioxide, partly as a result of life processes. Plants necessarily preceded animals in Earth's evolutionary scenario, and a waste product of their photosynthetic activity, free oxygen, is released to the atmosphere. One molecule of oxygen is released for every molecule of carbon dioxide that is incorporated into the tissues of plants. The respiration process of animals, bacteria, and even plants reverse this process as oxygen is consumed and carbon dioxide released in the course of an organism's metabolic processes.

The excess of oxygen relative to carbon dioxide in our contemporary atmosphere is a consequence of a bottleneck in this cycle. The dominant global sink for carbon is the vast reservoir of marine plankton remains, which is stored in the sediment layers of the oceans. Over a period of time both biological and chemical processes recycle some of this bound carbon back to carbon dioxide, which is dissolved in seawater. This gas is ultimately released when, in the course of ocean circulation, the deep waters return to the ocean surface where the excess carbon dioxide escapes to the atmosphere. However, most of the carbon contained in the deep sediment reservoir is released through an even slower process, the uplifting of this ocean sediment material at the oceans' margins. When exposed to the atmosphere, chemical weathering processes consume oxygen and release carbon dioxide from the ancient sediments.

Within the last decade we have learned from the isotopic content of these deep-sea sediments and from the chemical composition of bubbles of ancient atmosphere trapped in polar ice that the balance between atmospheric carbon dioxide and oxygen undergoes changes during glacial to interglacial transitions. These ice age cycles have occurred about every 100,000 years over the last million years.

Perturbing the Greenhouse

With the increasingly rapid development of our industrialized society in the last century and a quarter, we have accelerated the rate at which carbon is being returned from one of the compartments of the sediment reservoir to the atmosphere. The combustion of fossil fuels extracted from sediments of ancient inland and marginal seas is now resulting in higher concentrations of carbon dioxide in the atmosphere than have occurred at any time in the last few hundred thousand years.

An additional factor, the magnitude of which remains difficult to estimate, is the role that terrestrial biota, particularly forests, play as reservoirs for carbon. In the last several hundred years it has been common practice to clear forests as new territories are settled. In much of northern Europe and North America these forests have reestablished in the course of several decades. In tropical regions, however, it is clear that this process is much less likely to be reversed on such time scales.

To the degree that the biomass in tropical forests is currently being diminished without compensatory increases in biomass elsewhere, the process of deforestation represents a net flux of carbon to the atmosphere.

What is clear from the last few decades of research is that the finely tuned climate system of our planet is being perturbed. Earth is the warm hospitable place it is as a result of the "greenhouse" gas effect. Certain naturally occurring gases like water vapor, carbon dioxide, and ozone provide an insulating blanket, without which the surface temperature of the planet would, on average, be near the freezing point of water. However, the anthropogenically mediated flux of carbon from the sediments to the atmosphere is increasing the concentration of one of the important greenhouse gases in our atmosphere. Atmospheric modelers report that the effect of this increase in atmospheric carbon dioxide together with the combined effect of other greenhouse gases under human influence, such as methane and the freons, is leading our planet into a period which will be warmer than any which has occurred in the last several hundred thousand years.

The consequences of perturbation to the climate system of our planet cannot, at this time, be predicted with much confidence. There are too many unknowns in the nature and regulation of key couplings between the physical and biogeochemical aspects of climate forcing and feedbacks to predict the details, such as regional effects and timing, of the response.

A Program to Study Global Change

Within the last six years leaders of the earth, ocean, and atmospheric sciences communities in the United States have taken the initiative to encourage a new comprehensive effort that will strive to understand the fundamental nature of that thin film between the solid earth and the atmosphere, but including the oceans, that sustains life on our planet. This initiative was taken to the international scientific community, and the October 1984 General Assembly of the International Council of Scientific Unions (ICSU) launched a two year study to forge a new international scientific effort that would focus on this need for understanding, but with a particular sense of urgency given the documented and predicted changes in this system as a result of the hand of man.

The report of this study was presented at the 1986 General Assembly, and acting on the recommendations of this report ICSU launched the "The International Geosphere-Biosphere Programme: A Study of Global Change". The objective of this program is:

> To describe and understand the interactive physical, chemical, and biological processes that regulate the total Earth system, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions.

In concentrating on these interactive processes, the IGBP will put less emphasis on studies that, though they have great strengths and momentum of

their own, are already being addressed in existing initiatives, or that will less clearly contribute to our understanding of the changing nature of the biosphere on timescales of decades to centuries.

Priority in the Program will be given to those areas that deal with the key interactions among biological, chemical, and physical processes which on a global scale are most likely to:

1) Undergo significant change in the biosphere on time scales of decades to centuries,

2) Be susceptible to human perturbation, and

3) Lead to practical predictive capability.

To further define and plan this program ICSU appointed the Special Committee for the International Geosphere-Biosphere Programme (IGBP): A Study of Global Change. It has 18 members from 15 nations and an Executive Director who manages the secretariat for the committee.

Unlike the ICSU sponsored International Geophysical Year (IGY), which took place in 1957-8, the IGBP will require a decade or more of intensive effort. In a letter just now being sent to the National Members of ICSU, Sir John Kendrew, President of ICSU states:

> The IGBP will certainly be the most ambitious, the most wide-ranging, and in its impact on our understanding of the future possiblities for mankind the most important project that ICSU has ever undertaken. Its purpose is to study the progressive changes in the environment of the human species on this earth, past and future; to identify their causes, natural or man made; and to make informed predictions of the long-term future and thus of the dangers to our well being and even to our survival; and to investigate ways of minimizing those dangers that may be open to human intervention. From the point of view of fundamental science it is the extended study of the dynamics of the whole earth system - its geology, its oceans, its atmosphere and its climate, and the thin green layer on its surface that we call the biosphere; a scientific enquiry offering immense intellectual challenges and rewards. So the Programme will be scientifically exciting as well as immensely significant in charting the future of our species. It will necessarily continue for many years and will require the most sophisticated techniques and the most powerful computers. It will be a major endeavour of the scientific community in every country of the world.

The first meeting of the Special Committee was held in Paris in July 1987, and the second meeting has just concluded in Boston. The primary agenda item at the first meeting was the identification of topics for initial emphasis and a mechanism to proceed with planning the research of the IGBP. The ICSU Unions and Scientific Committees are kept fully informed regarding activities of the Special Committee, and are invited to engage

in joint ventures on topics of mutual interest.

The development of predictive capabilities will require cooperation with ongoing and planned research on global simulation models of the physical climate system. The use of such models in guiding the IGBP will be essential and in the initial phase existing global climate models will be modified to include relevant biogeochemical processes.

Accordingly, the Program will initially emphasize the acquisition of information that is necessary to understand more completely the cycling of key elements among the terrestrial ecosystems, the oceans, and the atmosphere, taking into consideration the natural and anthropogenic factors affecting these cycles, and the interactive effects of climate-induced feedbacks within and between the biosphere and atmosphere.

During the course of the first meeting certain underlying themes emerged which will receive special emphasis throughout the development and implementation of the IGBP. Each will contribute to the unique character of the scientific core of the Program, but because of their pervasive nature, it would be difficult and of questionable value to single them out for individual programatic development. They are as follows:

Documenting and Predicting Global Change
We must identify natural processes contributing to global change by studying the record of the past; assess the effects of current anthropogenic impacts on the coupling of biogeochemical processes and the physical climate system; and test our understanding of these processes with predictive models.

Observing and Improving Our Understanding of Dominant Forcing Functions
The effects of external forcing by solar and orbital phenomena and crust-mantle processes are of great significance across the full breadth of IGBP-related research. In addition, attention must be given to indeterminate natural forcing that arises from inherent short-term instabilities in the earth system.

Improving Our Understanding of Transient Phenomena in the Total Earth System
Key interactions among physical, chemical, and biological components of this system will be nonlinear; we must be able to describe them in order to assess their potential to produce rapid changes and sharp spatial gradients.

Assessing the Effects of Global Change That Would Cause Large-Scale and Important Modifications in the Availability of Renewable and Nonrenewable Resources
To do this we must focus on certain activities in sensitive areas most likely to be affected; we must also use the global-scale understanding to develop predictive capability at the regional scale.

The committee decided to proceed with problem assessment and research planning via two paths. One involves Coordinating Panels that focus on

geosphere-biosphere interactions where definition of the IGBP role needs specification. The other path involves Working Groups that focus on implementation aspects of the program.

The initial activities along each of these paths include:

Coordinating Panels on:
Terrestrial Biosphere-Atmospheric Chemistry Interactions
Marine Biosphere-Atmosphere Interactions
Biospheric Aspects of the Hydrological Cycle
Effects of Climate Change on Terrestrial Ecosystems

Working Groups on:
Global Geosphere-Biosphere Modeling
Data and Information Systems
Techniques for Extracting Environmental Data of the Past
Geo-Biosphere Observatories

At the second meeting of the Special Committee in February 1988 the preliminary reports of the Coordinating Panels and Working Groups were reviewed. These provide an outline of current and planned activities, particularly in the context of large scale scientific efforts both ongoing and planned. They serve to sharpen the focus of IGBP related objectives, and form the basis for more detailed reports that will be presented at the IGBP Scientific Advisory Council in October.

The Scientific Advisory Council meeting will include representatives from all National Members of ICSU. About twenty nations have formed or are now in the process of forming their national committees for the IGBP. In the U.S. this is the role of the newly formed National Academy of Sciences Committee on Global Change, which is chaired by Professor Harold A. Mooney of Stanford University.

Much of the IGBP will consist of highly complementary national efforts with the Special Committee having responsibility for coordination of planning, analysis, and synthesis. In many nations the enthusiasm, both among scientists and within governments, for the IGBP is running high. Strong statements of support came from the Australian, Canadian, and Soviet delegates at the meeting of the United Nations Committee on Peaceful Uses of Outer Space just a few weeks ago. Among my colleagues in the Soviet Union there is a sense that the IGBP will lead to unprecedented opportunity for Soviet-U.S. scientific collaboration, and indeed we are all buoyed by the agreement reached during the recent Reagan-Gorbachev summit to:

> "promote broad international and bilateral cooperation in the increasingly important area of global climate change".

It is imperative that governments plan now for serious commitments to this endeavor, realizing that the global scale understanding necessary to predict regional effects of global change will require long term studies that may not be expected to yield practical applications for several years to decades. Moreover, both the access to national territories and

exclusive economic zones and the sharing of data among all participating scientists and governmental bodies are essential to the success of this program. We have talked very frankly about these topics in the sessions of the Special Committee, and to a person we are optimistic that further discussions such as those recently begun by President Reagan and General Secretary Gorbachev will lead us into a new era of scientific opportunity.

U.S. Support for the IGBP

Within the United States key components of this program are being developed and implemented under individual agency banners such as Global Geosciences within the National Science Foundation, Earth System Science within the National Aeronautics and Space Administration, and Global Climate Change within the National Oceanic and Atmospheric Administration. Complementary commitments to this program are now being formulated by other agencies that share in supporting the coordinating activites of the NAS Committee on Global Change. Interagency coordination is the responsibility of the Office of Science and Technology Policy's Committee on Earth Sciences.

An essential requirement of this program is a global observing system, a significant component of which is a suite of proven and next generation satellite sensors. The foundation of a predictive capability for global change must be built upon a reliable base of observations, and the refinement of these predictions with time requires continuing documentation of the changes that are occurring. Most of the satellite sensors with application potential for these research issues have become available only in that last decade, and yet with data sets spanning a few years, or only months in some cases, these products have revolutionized our concepts of the planetary dynamic.

LANDSAT imagery, initially with the Multi-Spectral Scanner, and more recently with the Thematic Mapper, now permits detailed characterization of regions where our studies must be focused if we are to document and understand the underlying processes responsible for global change. These data have proven to be extremely valuable to the scientific community. The continuity of this observational capability is essential for the detailed documentation of changes for the areal extent, the community composition, and to some degree even the physiological state of terrestrial vegetation.

A related capability for remotely sensing the distribution of plankton in the ocean is also a possibility for the next LANDSAT satellite. This candidate sensor, known as SeaWiFS, is a wide-field instrument that uses technology similar to that proven to be of immense value for ocean studies with the now defunct Coastal Zone Color Scanner (CZCS) launched as a proof of concept mission in 1978 on NIMBUS-7. This is a very clear case of U.S. leadership in space research. No other nation has flown such instruments, and scientists of many nations covet our capability to use ocean color data. As a result of the efforts of several U.S. scientists, particularly groups at Goddard Space Flight Center and the University of Miami we now have an entirely new way of viewing biological processes in the ocean. For example, ocean scientists can, for the first time, study the processes responsible for marine plankton photosynthesis and the flux of carbon into the deep-sea on time and space scales appropriate to an understanding of

the influence of climate on these ocean processes and vice versa. Two examples of these products are attached. Although both are in their preliminary phase, they are useful here for demonstrating the power of both the global scale and temporal scale of these observing systems.

The first is a composite of all CZCS data collected during the eighteen month period from January 1979 through June 1980. The color coding used ranges from red for high concentrations of plankton to blue for low concentrations. Some areas of the ocean remain opaque in this composite because the instrument was operated only intermittently in this proof of concept mode, and some areas of the ocean are regularly covered by clouds and sea ice. General patterns of plankton distribution, low in the central gyres, and high along the coasts, particularly in upwelling regions off the coast of South America and Africa, are rather as one would have predicted from decades of shipboard observations. But because shipboard observations are labor intensive they have been and always will be spotty in time and space. Our view of theequatorial ocean regions, for example, has changed dramatically as a result of these data. Composites like this are particularly useful when compared to the same region at a different time. We are only now coming to recognize the magnitude of interannual variability in ocean processes, and its implications for climate.

On a regional scale, the seasonal cycle of biological activity is readily apparent, and this can be seen in the second image for the North Atlantic in 1979. Again the intermittent operation of the CZCS resulted in some areas without data. What is particularly evident is the development of the spring "bloom" of plankton. This provides the base of the food web for important commercial fisheries in this area, but it is also an important process by which carbon dioxide is drawn into the ocean to compensate for the photosynthetic consumption by plankton. The data shown here for a single season represent hundreds of times more data than all the observations oceanographers have been able to gather from ships in this region over the last few decades. This capability now permits us to pose hypotheses as to how physical processes in the atmosphere and ocean determine the timing and extent of bloom phenomena throughout the world's oceans. Scientific accomplishments such as these in developing satellite sensing systems and applying their products to our understanding of couplings between physical and biogeochemical processes that affect climate has been the cornerstone of U.S. leadership in the study of global change.

In the immediate future we need to secure the continued government support that is necessary for both the LANDSAT program (including SeaWiFS) in the private sector, and the science agency support for the global change related research that depends on data from these sensors.

Over a broader time span, to the mid 1990's and beyond, the research focus of the IGBP will require a comprehensive earth observing capability. In Dr. Sally K. Ride's 1987 report to the Administrator of NASA on "Leadership and America's Future in Space" she outlines four "leadership initiatives", and in that referred to as "Mission to Planet Earth" she provides a blueprint for this capability. Her report makes the case for earth observations, and describes the types of satellite sensors required, and how the data will be used. She makes the point that the "U.S. is the

only country currently capable of leading a Mission to Planet Earth", and while drawing attention to the need for international cooperation in this endeavor, she states that this is an "important opportunity for the United States to exercise leadership in an increasingly significant area. This strategy is examined in detail in the report of the Earth System Science Committee of the NASA Advisory Council, and the first facility will be the Earth Observing System (Eos) which is in the Administration's budget for Advanced Technology Development in FY 1989. This next generation capability for earth sensing requires two polar orbiting satellites, which are being planned cooperatively by the European Space Agency and Japan. The stated goal of Eos is to advance the scientific understanding of the entire Earth system on the global scale by developing a deeper understanding of the components of that system and the interactions among them, and how the Earth system is changing. Substantial documents detail the capabilities of the candidate sensors, and demonstrate the value of these observations in a study of global change.

The U.S. scientific community has been very influential in developing the concept of the IGBP, and the U.S. Science funding agencies have taken the lead in developing and demonstrating proof of concept for the critical remote sensing component of this effort. Interestingly, this role of leadership has been welcomed internationally. While no other nation can equal our capability in the area of space research related to global change, we find the European Space Agency and Japan eager to cooperate in developing and operating particular sensors. Scientists of nations that lack space research capabilities are eager to share in the complementary ground based aspects of this study.

If we are to keep this community of scientists engaged, we must do everything possible to avoid repeating the FY 1988 budgetary catastrophe for this science. In addition, we must work to insure that the plans for imminent NASA missions necessary for ocean physics, and the EOSAT missions necessary for terrestrial and ocean biology come to fruition. At the same time we must strive to keep the Eos on track for a new start in 1991.

Many of us in the scientific community do not believe that within NASA the proposed Mission to Planet Earth is getting visibility equal to that for the other "leadership initiatives" Dr. Ride identified relating to exploration of the solar system and astronaut landings on the Moon and Mars. In Dr. Rides own words, "NASA should embrace Mission to Planet Earth. This initiative is responsive, time critical, and shows a recognition of our responsibility to our home planet."

(The CZCS images attached were provided courtesy of Dr. Wayne Esaias and Dr. Gene Feldman, Goddard Space Flight Center, Greenbelt, Md 20771 (301/826-5465 or -9428, respectively). Contact them regarding additional information or permission to distribute these images.)

Senator KERRY. Dr. McCarthy, thank you.

I just want to ask a couple of questions of each of you after you speak, and then we will do perhaps a general discussion. But let me just ask you quickly.

You have obviously made a lot of progress in terms of the geosphere-biosphere project, collaborating with the Soviets. How would you characterize that state of collaboration at this point in time?

Dr. MCCARTHY. The planning committee I referred to has two Soviet members. It consists of 18 people from 15 nations. And I would say that the Soviet members were as buoyed as American scientists by the statement contained in the Reagan-Gorbachev summit announcement which, to quote, was "to promote broad international and bilateral cooperation in the increasingly important area of global climate change."

The Soviet scientists were delighted that their national leader was prepared to make such a statement, as I think the American scientific community was as well.

Senator KERRY. Are there certain areas which lend themselves best to that kind of collaborative effort, and if so can you tell us what they are?

Dr. MCCARTHY. I think that there are several aspects of the observational capability, both space and land-based, that the Soviets are very interested in. There are several strengths in the Soviet Union, several research strengths that I think complement nicely those in the United States. And one of the tasks of our committee is to identify where we can best play on those national strengths in putting together an international program.

Senator KERRY. In your written testimony, you emphasize the importance of Landsat in providing data. Obviously, we are troubled as to what the availability of that is going to be at this point in time.

Is the information provided by Landsat available to us from the French or the Soviet remote sensing?

Dr. MCCARTHY. Well again, Landsat is an example where we had the lead in space. It was a U.S. capability that first brought us the Landsat type images. Certainly there has been great, great uncertainty in the scientific community as to what the future for Landsat would be as we have gone through the transfer of the Landsat capability to the private sector.

It is my understanding that that is moving along very well, and by the 1st of April we will have an agreement between the government and EOSAT that will lead us to the next generation Landsat instrument, scheduled for launch in 1991, both with the land sensing and ocean sensing component.

Admittedly, the Spot Image data are similar in many regards and would be useful for the same scientific purpose. They are, of course, not as accessible to American scientists as is the Landsat data. And of course, the Soviets are also developing a similar capability, and we know nothing yet about the accessibility of that capability.

Senator KERRY. Now, even if that contract for Landsat VI is negotiated successfully, there is going to be a gap, is there not, between Landsat IV and V's demise and the launch of Landsat VI, which means that we are going to have a gap in terms of the U.S. data-gathering, are we not?

And what is the effect of that, if that is true?

Dr. MCCARTHY. It is a great concern certainly for many areas of the earth, which are changing rapidly. Again, Dr. Mary Cleave referred to being able to see land use patterns. One can see the encroachment of deserts into areas that were once vegetated.

We will have a hiatus in our own national effort. Now, Landsat IV and V are flying at this time. It is not certain whether they will last until 1991. The same is true for our ocean color capability, which we have not had for over a year now, and would not have again until at the earliest time in 1991.

Senator KERRY. Well, I think you have very graphically demonstrated to us yet another area of concern, and I thank you very much. And we are going to come back to some general questions if we can.

Dr. Kenney, if you could pick up, please.

STATEMENT OF DR. GEORGE B. KENNEY, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. KENNEY. Good morning, ladies and gentlemen.

Senator Kerry, thank you for the opportunity to address this subcommittee. I have been asked to talk about the materials processing center, the center of excellence in materials processing at MIT, its current research activities, and some of their future implications, but also to speak to the levels of industrial interaction that we have and how we interact with the educational process.

I would like to first begin by defining what materials processing really is. And with that, let us begin. Materials processing is the engineering field that seeks to control structure, shape, and properties of materials and to do so in socially and economically cost effective ways. That rather dry definition sticks in even my throat, and so let me tell you really what materials processing is all about.

It started about 5,000 years ago when artisans began working with materials to enhance their esthetic appeal and utility. For example, in Asia Minor artists were working with pottery, clay, and basic metals, trying to develop new instruments and articles of art.

A thousand years ago the Japanese were making the incredible steel going into the samurai swords. We had iron-making during the Middle Ages, leading up to the ubiquitous American blacksmith, who effectively made the plowshares with which this country was first plowed.

Going beyond that, let us talk about steel. Steel really was introduced into this country around the turn of the century, and it was with steel and the processing of steel that we built the railroads and bridges and skyscrapers, et cetera, that we now call America.

Beyond steel, we go to aluminum, which came about in the late fifties, actually fifties and sixties. And it was aluminum that made aerospace and aeronautical travel possible. A 747 would not go very far if it was made from the materials that the Wright Brothers used, balsa wood and a little canvas, et cetera.

So materials have essentially given us the opportunity to create new technologies which add to our society. Beyond aluminum in the fifties, we go to plastics in the sixties. And all of you who remember The Graduate know that the sixties were the years of plastics: "Plastics, my boy."

The seventies, what was the material of the seventies? Silicon, and it was silicon that made the computer revolution and the computer really possible. Without silicon and the semiconductor industry, we would not be where we are today.

Beyond the seventies, we get to the eighties and we can think in terms of silica for optical communication, opto-electronics, et cetera. And we get into the eighties and we start talking about advanced ceramics—engines, materials to clothe the shuttle to withstand the re-entry temperatures, et cetera.

We get ourselves to the point where we clearly recognize the fact that materials and materials processing technologies are really the foundation upon which other more advanced technologies rest.

Without these materials, we would not have the communications systems we have, transportation systems we have, computation systems we have, et cetera. And so advanced materials are the foundation upon which leadership, our economy, and competitiveness are based.

Let us go back to space processing materials. Late in the 1970's, both MIT and NASA recognized that in materials processing we really did not understand enough about the basic science. We knew how to heat it and beat it, but we really did not understand the basic science behind it.

And it was at that point that NASA founded the materials processing center at MIT with a $300,000 initial block grant. The Center of Excellence in Materials Processing at MIT was founded.

Since then we have grown to just over $7 million. 50 percent of that still comes from essentially government agencies, 13 percent or $900,000 from NASA, and the remaining 38 percent comes directly from industry. We have about 90 faculty and staff and 90 graduate students working.

But what have we been doing? Well, back in 1973, if we go back to the beginning of the NASA program, one of the early success stories was single crystal growth, single crystal growth in space, conducted initially by Professor Witt, who had an experiment aboard Skylab.

That first experiment proved one thing. That is, that we did not know much about what we were doing. While we got a very interesting crystal, we did not know quite how we got it. We did not understand the basic science.

The second flight on the Soyuz-NASA joint program basically confirmed that we could in fact grow very, very high quality single crystals in space, based upon one unique phenomenon.

May I have the first slide.

And that is the microgravity environment of space. In space with microgravity, we have the advantage with microgravity of eliminating convection. Basically what that means, when you put a pot on a burner in your kitchen, it boils and boils over and you get convection.

And when you are trying to grow a single crystal—and by the way, growing a single crystal is very similar to making candles. How many of you have ever drawn candles? It is very similar. You draw the single crystal from the melt and if that melt is rolling over you can get all kinds of impurities.

Also, in space you do not get separation. There is no real buoyancy and no separation. The bottom line is you are able to produce a very, very high quality single crystal. The interesting thing here is that those

first experiments really did demonstrate a whole new processing technology for silicon.

That technology was commercialized in the mid-eighties and now is the standard for single crystal growth worldwide. One other interesting thing that happened, that single crystal growth is done in a magnetic field. In fact, that magnetic field was developed first at MIT to really simulate a microgravity environment.

In other words, with a magnetic field around this pot of molten silicon, you can effectively on earth eliminate some of this convection to approach this situation and grow very, very high quality silicons and crystals. That is one experiment.

The formal details of other experiments that we have done is in the testimony, and I leave that to you. With respect to education or industrial interaction, one of the things that the center did right from the beginning was engage in active participation with industry, to the extent that now we have an industrial advisory board consisting of 26 members. We actively interact with over 65 companies from around the world on advanced materials technologies, and we are engaged in four major multi-client research programs with industry that engages another 59 companies, again from around the world.

On the educational side, based on the support of industry we have been able to over the last five years provide something like 35 direct fellowships to students studying in advanced materials and advanced material technology, many of whom have been working with the space program at MIT.

One of the other programs that we have is in scholarships. We provided over 25 scholarships to undergraduates to encourage them to engage in graduate education at MIT in materials processing, and again this year we will offer something like eight of those fellowships.

I would like to announce in closing this testimony that one of those, one of those fellowships from this date forward will be designated the Microgravity Science Fellowship. In other words, we recognize the importance of space processing and the contributions of space processing to our field and our field of technology to the extent that we are willing to support it ourselves based on the industrial support that we have so that we can bring together the appropriate partnership of industry, government, and universities.

Thank you.

Senator KERRY. I always thought the material of the future when I was growing up was Silly Putty.

We would love to hear from you, if you would, some of the practical applications of the research that has been done at the facility with respect to the manufacturing process. Could you share that with us a little bit?

Dr. KENNEY. Yes. Explicitly, that single crystal growth that I talked about, conducted in the mid-seventies, was converted to full commercial practice in the early 1980's. That single crystal growth process is where in fact the crystal is grown in a magnetic field on earth.

The first use of that magnetic field was to dampen out convection, to give us some analogue to space processing. Well, it turned out that it did generate some of the benefits of space, and in fact today single crystal growth technology called magnetic crossing single crystal growth or bridging is essentially the commercial standard of today.

So in fact, research conducted 13, 15 years ago did find its way directly into research.

Some experiments that we are running today have to do with levitation and undercooling of metal products. One of the more interesting areas of materials are metastable materials, an area based on rapid solidification. The problem with rapid solidification is that you are able to fool mother nature to a certain extent and create whole new structures that are not available to you in normal practice, giving you properties and performance way beyond what we are normally used to.

Some of the space experiments that we are doing specifically probe the solidification process. Unless we understand how the material freezes, how it solidifies, we really cannot generate and extract those properties we are looking for.

And one of the experiments that actually flew in January of 1986 looked at how essentially a levitated container-less product, essentially a one centimeter cube of liquid metal, froze. And it told us some very—it gave us some very interesting information, insight, insight that will be useful again for processing in space, but just as importantly, if not moreso, give us insight into how we process our materials here on earth, which again will support that economic competitiveness issue.

Senator KERRY. How would increased space flights directly enhance your efforts, for instance, to develop new materials such as ceramic superconductors?

Dr. KENNEY. Again, it is those same issues of solidification, structure, and structure control to process control that directly relate to the performance and properties that we get. We do have to look at those basic processing fundamentals, and it is only then that we will be able to control the structure of these new superconductors.

The interesting thing about these new superconductors—and I presume you are referring to the high temperature superconductors. They were really only invented or discovered less than two years ago.

We have been able to conduct effectively 30 years of research in the last year, based upon level of effort alone. We are going to have to understand at a more fundamental level the structure and control the structure in those systems than we are in the systems we are currently dealing with.

There I think space-based processing and circumstances is going to give us again that insight that we are going to need to get the structures that we are looking for. The thing to remember about materials is that it is only through control of the process that you get the structure that you are looking for, and that structure is what gives you the properties and performance.

And so it is a very critical time line development and sequence.

Senator KERRY. Do you believe—a last question perhaps, but do you believe that the discussion about factories in space and space-based manufacturing and so forth shifts the debate from where it ought to be, which is essentially on a sound, clear applied science manufacturing program?

Dr. KENNEY. I think both are necessary. I think we need a clear applied science program, basically to understand better what we are doing here on earth. But if we do not have that clear applied science base in materials processing, the factory of the future will not really be possible, because we will not have the fundamental understanding of the processing in space necessary to do it there, although I do believe that processing in space will have—will pay some very, very interesting benefits, both in the structural materials, biomaterials, and in particular, very exciting in that area with respect to separation and purification, et cetera.

Senator KERRY. You do not see any degree to which one is racing ahead of the other at this point, or to the degree that the manufacturing base in space is getting ahead of the applied science base?

Dr. KENNEY. From my perspective, I do not see that happening again. I have a limited view of that world. We cannot all see all things. We will know whether we are ahead of ourselves with respect to manufacturing in space based on the results of the first few experiments.

If we understand what we are getting, then we will have the right mix of manufacturing in space and science in space. We learned those lessons very early with the single crystal growth, for example. We got some very fascinating results that we did not quite understand, most of which we understood, but only when we better understood the science base, but to go back and really perfect what we were trying to do.

So it is going to be a good combination and one will tell on the other.

Senator KERRY. Would you say that the United States is the leader in materials processing and microgravity research?

Dr. KENNEY. In microgravity research, yes. Materials processing in general, I cannot be quite as optimistic.

Senator KERRY. Thank you very much, Dr. Kenney. We appreciate it.

[The statement follows:]

STATEMENT OF GEORGE B. KENNEY, ASSISTANT DIRECTOR, MATERIALS PROCESSING CENTER
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

The opportunity to appear before this Senate Subcommittee to discuss the activities of the Center of Excellence for Materials Processing at MIT, its ongoing areas of research, potential areas of application, contributions to the educational process, and industrial interactions, is greatly appreciated.

The microgravity environment of space provides a new dimension for research and development of materials and materials processing. The near absence of convection in liquids and the capability of containerless processing, both possible only in this unique environment, provide many particularly exciting and potentially fruitful opportunities. In particular, these unique processing conditions provide not only new experimental materials and processing data, but also the potential for enhancing existing and developing new, commercially viable materials processing techniques. In fact, NASA's low gravity research platforms provide a unique opportunity to obtain valuable information and insight critical to the understanding, control, and efficiency of both terrestrial and potential extraterrestrial materials processes. Thus, NASA's mission and the impact of microgravity studies is much broader that just materials research and processing in space in that if affects industrial production and productivity in general. NASA recognized this potential for both research and commercial development and, as only one component of their effort, served as Founder in the establishment of the Materials Processing Center at MIT.

THE UNIQUE FEATURES OF MATERIALS PROCESSING IN SPACE AND NASA'S GOALS

Before discussing the Materials Processing Center (MPC) and its activities, it is very important to first identify some of the features of space which make it a unique laboratory for materials research in general. These features include:

1. A low gravity environment (10^{-5} to 10^{-6}g);
2. A vacuum of essentially unlimited pumping capacity;
3. Unique radiation conditions (O K absorber); and
4. The unlimited dimensions of space.

The most important of these feature to materials processing research is the microgravity environment. The benefits of access to a laboratory with a reduced gravitational force or near weightlessness are:

1. The absence of convection;
2. The opportunity to study weak, secondary forces, such as surface tension driven convection; and
3. The opportunity to react and process materials in the absence of a fixed container, thereby eliminating inherent container contamination problems and related operating temperature restrictions.

Prior to the shuttle program in the 1970's, NASA focused its efforts on experiments directed at primarily high value-added products which might be manufactured in space. However, the results of early experiments soon made it all too apparent that a better understanding of the science base of materials processes was required in order to interpret the effects of unique phenomena observed when materials are processed under microgravity conditions. For example, the elimination of gravity-driven convective flow in space revealed the unexpected presence and influence of weak, secondary, surface-tension-driven flows. It was necessary to quantify the nature of these newly identified flow phenomena in order to interpret the results of the materials processing experiments being conducted in space. Consequently, NASA reorganized its Materials Processing in Space Division in 1978, expanded its functions, and renamed it the Microgravity Science and Applications Division in 1983. Its goals are:

1. To use the microgravity environment as a laboratory (a) to obtain understanding of basic physical phenomena and processes, (b) quantify limitations/effects imposed by gravity on these phenomena and processes, and (c) apply basic knowledge to specific processes or products for applications either unique to space or Earth.

2. To expand, centralize, and disseminate the research data base as widely as possible to the US private sector.

To achieve its goals, the emphasis at NASA shifted toward the establishment of a strong scientific base for space experiments. Fundamentally sound ground-based research programs soon became a prerequisite to flight experiments. It was also realized at this point that space-based manufacturing should not be the primary goal. Instead, more emphasis was placed on conducting scientific and engineering research directed to expanding the knowledge of the fundamental factors determining the properties of materials, improving the processes by which these materials are made on Earth, and thereby improving the properties of existing materials and leading to the development of new materials.

ESTABLISHMENT OF THE MATERIALS PROCESSING CENTER AT MIT

By the late 1970's, mounting foreign competition had already begun to threaten American technological leadership in basic processing, such as steel and automaking, as well as our ability to build advanced systems. The Materials Processing Center was created in 1980 in response to a recognized national need to counter this threat by enhancing basic research and stimulating industrial innovation. In 1979, the National Research Council reported that

> "The near absence in our universities of research in materials-processing and manufacturing technology denies the country a potential source of new ideas and innovation. Furthermore, it means that the universities are not exposing young people to current advances in the field." *

During the previous 25 years, considerable attention and government funding had been focused on materials science, the fundamental study of structure and structure-property relationships. The engineering side, particularly materials processing, had taken a back-seat in terms of research expenditures, academic interest, and creative output. Yet, when considering specific national technical needs, the field of materials processing is often of central importance. America's productivity and ability to produce competitive advanced electronics, communications, aerospace, energy, and transportation systems are directly coupled to advances in materials processing and manufacturing technology.

In many ways, advances in the development and processing of new materials have and will continue to serve as the foundation and catalyst upon which innovative new products, processes, and technologies are based. Obvious recent and current examples include silicon, which serves as the standard of today's solid-state electronics industry and silica, the foundation upon which the current revolution in optical communication systems is based. The new high Tc ceramic superconductors are but the latest example of a new material with the potential to launch another technological revolution with immense societal, economic, and competitive implications for growth on a global scale. The dominance of technology and innovation over capital as the primary driving force for economic growth, while not fully appreciated in all financial, managerial, and political circles, is not a new concept. This fundamental economic principle was first quantified nearly 30 years ago by Professor Robert Solow, for which he won the 1987 Nobel Price in Economic Science.

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*Science and Technology, A Five Year Outlook, National Research Council, W.H. Freeman Co., San Francisco (1979).

Recognizing this national need to enhance the science base necessary to support American productivity and competitiveness, MIT's Materials Processing Center was created to bring together the faculty, staff, and students necessary to contribute effectively to broad materials processing problems and opportunities. For the past eight years, the Materials Processing Center has provided a focus and forum in which academic, industrial, and government personnel can broaden their knowledge while collaboratively developing new scientific and technological skills in materials processing. A key component of this effort is the expansion of the talent base by the recruitment of top students to the field of materials processing.

It was the convergence in the late 1970's of NASA's need to establish a science base in support of materials processing in space experiments, a recognized national need to support American productivity and competitiveness via innovative materials and processing development, and MIT's ongoing efforts in both of these areas that catalyzed the founding of the Materials Processing Center.

CURRENT STATUS OF THE MATERIALS PROCESSING CENTER

The Materials Processing Center was founded in 1980 with an initial block grant from NASA of $300, 000, to establish a research base in materials processing. The Center has expanded steadily to a total research volume which exceeded $7 million in 1987, which makes it now the third largest research center in MIT's School of Engineering. NASA continues to support the Center with the ongoing $255,000 block grant, plus $680, 000 in additional contracts that are administered through the Center. This represents roughly 13% of the Center's total funding support. This initial and continuing NASA support has been leveraged to promote research activities of particular relevance to not only the Space Program, but to other governmental and industrial concerns as well. Industrial sponsored research activities account for $2.5 million or 36% of the total funding. The remaining 51% of the Materials Processing Center's funding is provided by various government agencies. More than 43 faculty and 44 research staff members, plus 90 graduate students are currently involved in ongoing research programs.

A recurring theme throughout all MPC research is the inter-relationships of **Structure-Properties-Performance through Processing**. Contemporary engineers integrate modern physical science and innovative technologies with age-old methods to create materials with properties previously unknown or unimaginable. The recent production of manometer structures in ferrous materials and the new, high-temperature, ceramic superconductors are excellent examples. Materials science and processing have proven to be both vital and limiting to the evolving era of communications, computation, transportation, and power generation technologies, among others.

The founders of the MPC realized that the problems facing modern industry are not readily approached or solved by a single discipline or an individual staff member. The MPC has therefore enlisted the aid and resources of faculty from many diverse disciplines,thereby linking otherwise isolated research teams.

Besides facing problems spanning many disciplines, materials scientists must keep pace with the ever-increasing rate of technology change. Whereas the succession of Stone, Bronze, and Steel Ages can be measured in millennia, the flow of present-day materials development causes changes in decades, years, or even months. Consider, for example, the transistor. Since its invention three and a half decades ago, it has fundamentally changed not only American society, but the world's. But even the amazing speed of technological change brought about by the transistor may be eclipsed by the catalyzed by the new, high-temperature, ceramic superconductors. The pace of progress and intensity of effort in ceramic superconductor research has packed the normal equivalent of thirty years of research effort into only one year. The MPC links industry and government to MIT researchers, ensuring the timely transfer of new materials and processing methods from the realm of basic science to that of practical commercial applications.

Technological change has been propelled by unprecedented developments on three fronts: (a) new experimental techniques to study structure and properties, (b) innovative processing of materials, and (c) powerful new methods for theoretical analysis and modeling. New theoretical and experimental tools provide today's materials engineer with the means to create new and improve existing materials processing technologies.

THE RESEARCH ACTIVITIES OF THE CENTER

The research activities of the Center cover a broad range of materials and processes:

Materials

- Advanced Ceramics
- Electronic Materials
- Polymers
- Metals
- Metal, Ceramic, and Polymer Matrix Composites

Activities

- Microgravity Processing
- Materials Economics
- Welding and Joining
- Electroprocessing
- Rapid Solidification
- Environmental Degradation
- Mathematical Modeling

During the past year, many of these activities have grown and branched out into new areas. Our industrially sponsored, advanced ceramics program continued to strengthen and has expanded to include a major new emphasis on the processing of the new high-critical temperature, ceramic superconductors. Research in electronic materials, environmental degradation of materials, and metal and ceramic matrix composites extended in new directions, building upon existing strong programs. Programs in microgravity processing, materials economics, welding and joining, electroprocessing, rapid solidification, mathematical physical modeling, polymer, and metals continued to flourish

During the past year, the MPC embarked on a number of new collaborative ventures that expand its research focus to include new areas of materials processing. New alliances with laboratories and other MIT centers, departments, and schools now enable the MPC to pursue innovative materials research in:

1. **High Temperature Ceramic Superconductors**: While these revolutionary materials pocess incredible commercial and defensive potential, the scientific knowledge base for these ceramic materials is only beginning to emerge. Faculty and staff from various sectors of our Center are actively collaborating with other department, centers, and laboratories throughout MIT and beyond to establish the necessary science base and processing fundamentals.

2. **Crystal Physics and Optical Electronics**: A new alliance with the CPOE Lab brings the MPC into a new research area - the science and technology of electrical, optical, and magnetic materials and their application in devices like diode pumped lasers, tunable solid-state lasers, sensors, batteries, low-loss IR fibers, photoelectrodes, and nonlinear electrical ceramics.

3. **Materials Synthesis Laboratory**: This new lab has been created at MIT in collaboration with the Los Alamos National Laboratory and Harvard University to develop a broad-based approach to the science of materials synthesis. Experts in electronic structure theory (molecular orbital chemistry), inorganic synthesis chemistry, crystal chemistry, and materials science will combine their talents in an attempt to understand the relationships existing among the processing, structure, properties, and performance of engineering materials. By developing a deep understanding of bonding and crystal chemistry, researchers hope to predict and synthesize entirely new families of solids that exhibit novel properties.

4. **Electronic Device Packaging:** The Center has entered into a new, interdisciplinary, problem-oriented research and development program with the Micro-Systems Technology Laboratory in the Department of Electrical Engineering and Computer Science at MIT. With a better understanding of device packaging technology, researchers hope to develop the basis for the synthesis of new polymeric materials that are technically and economically more effective than those currently available.

5. **Leaders for Manufacturing Program:** The Center has joined forces with other centers and departments in the School of Engineering and the Sloan School of Management at MIT to create this new program. While a logical outgrowth of good science, engineering, and management, it represents a radical departure from tradition. Based on new and creative relationships with industry, the program will rely on wholly new educational and research approaches to integrate technology and management programs. The research does not focus on the invention of new technology, but more properly on the implementation of appropriate technology.

MICROGRAVITY RESEARCH ACTIVITIES SPONSORED BY NASA

Based on the catalyst provided by NASA's initial founding block grant of $300,000, the Materials Processing Center has grown at a substantial rate and currently andministers a $7 million research effort at MIT. 13% of this total is NASA support which is specifically focused on the development of both a fundamental and applied knowledge of materials processing. While commercialization of space will benefit from the scientific foundation which is being established, commercialization of space per se is not the focus of this Center.

NASA BLOCK GRANT

NASA support of the Center of Excellence in Materials Processing at MIT consists of two specific components. The first component is the continuing NASA block grant which serves to attract and stimulate the faculty and staff within MIT to become involved in microgravity research. This continuing program has resulted in a broad range of research projects, and several new concepts and applications for microgravity research and processing.

One example of this is the project conducted by Professor Robert Rose to evaluate the potential of dielectrophoretic separation in the microgravity

environment. Dielectrophoresis , the motion induced on a neutral particle by the presence of a nonuniform electric field, has, in principle, several remarkable features. Since it depends principally on the complex electrical permittivity and acceleration is independent of particle size and shape, it could be used to separate particles based on materials properties only. It is, however, a second-order effect, and the resulting forces are weak and easily wiped out by convection or turbulence. These problems are completely eliminated by the use of the microgravity/vacuum environment. To assess the use of dielectrophoresis as a materials separation technology in microgravity and /or vacuum, Professor Rose designed and constructed a free-fall, vacuum dielectrophoretic separator. The apparatus has been used to evaluate the separation of "model" powder mixtures (ceramics, polymeric, metallics) with some success.

On an experimental basis, the dielectrophoretic effect has been used to sort mixed minerals and also populations of cells, eg., red blood cells, blood platelets, yeast cells, etc. The process is also capable of separating living from dead cells under some circumstances. Dielectrophoresis offers some unique advantages over electrophoresis and may serve in a useful complementary role in microgravity separation processes. Efforts are ongoing to secure funding to continue this research project.

In a separate project, Professor Thomas Eagar is studying the way braze metal flows into a joint. Considerable evidence suggests that braze joints can be as strong as weldments if defects at the joint are eliminated. Professor Eagar hypothesizes that instabilities in the braze metal interface as the metal flows into the joint causes many of the defects. By stabilizing the interface, it may be possible to produce exceedingly high quality and high-strength joints by brazing. Since both surface tension and buoyancy forces may dominate the flow of the braze alloy, comparing the flow behavior of joints produced on earth and in a microgravity environment should provide further insight into the process.

SPECIFIC NASA CONTRACT TASKS

All of the NASA-sponsored effort relates to gravitational dependent phenomena within materials processing techniques that are of interest to the Center. The specific research conducted by Professors R. Brown and A. Witt relate to the modeling of time-dependent flows during crystal growth and the experimental observation of the influences of convection on the quality of electronic crystals, respectively. These complementary projects are an excellent example of the complementary analytical modeling/experimental approach mandatory for sound space experimentation, and the interdisciplinary nature of sophisticated materials processes. For example, this ongoing single crystal growth experiment has required

the collaborative efforts of materials scientists and mechanical engineers to establish the empirical correlations and specific engineering designs, materials engineers to model the process dynamics, chemical engineers to model and specify the heat and mass flow conditions, and electrical engineers to provide information processing for overall process control. The benefits of such a program include a synthesis where none existed before and an accelerated rate of science and technology development. This particular single crystal growth program has been officially recognized by NASA for its outstanding success in space experiments.

The microgravity single crystal growth experiments of Professor August F. Witt were among some of the very first materials processing in space experiments conducted in 1973 aboard Skylab. Follow-up experiments in 1975 on the Apollo-Soyez Test Project (ASTP), during which NASA's Apollo docked with the USSR's Soyez, confirmed that buoyance-driven convective flows were sufficiently suppressed such that diffusion-controlled crystal growth could be approached. These two Skylab and ASTP experiments clearly demonstrated the unique characteristics and potential of a space laboratory. A uniformly doped InSb crystal had been grown free of the growth striations associated with terrestrial processes.

Professor Witt and his colleagues recognized very early on the importance and value of a sound process science base to support space experiments. In this regard, efforts were made to simulate the buoyance free convection conditions of space here on earth by imposing a strong magnetic field on the crystal growth melt in an attempt to suppress or retard normal , gravity induced, thermal convection. This was first accomplished by Professor Merton C. Flemings in 1969 for the Bridgeman crystal growth process. This application of magnetic fields to suppress convection during crystal growth was extended to the Czochralski process by Professor Witt in 1970. These two early space program crystal growth experiments are clearly responsible for the subsequent design and development of the most advanced crystal growth equipment and processing procedures used by industry today.

Much of the success of the crystal growth program is directly attributable to the very close collaboration of Professor Witt and Professor Robert Brown. Over the last seven years, Professor Brown has developed very sophisticated mathematical models of the crystal growth process. These models serve to provide the theoretical base for crystal growth phenomena. They also provide the linkage between theory and the experimental results obtained by Professor Witt. When validated by experimental data, the model can effectively serve to interpolate the effects of physical processing phenomena which cannot be directly measured and extrapolate known processing parameters in the design of crystal growth equipment or in calculating the effects of various physical phenomena and processing conditions in different processing environments. In one sense, the mathematical model serves to minimize one of the major problems in advanced materials processing, which is a lack of adequate

sensors. Professor Brown is also currently working collaboratively with other NASA-sponsored crystal growth projects at Grummond, GTE, and NASA's Huntsville facility.

Guided by the results of the early Skylab and ASTP experiments, and subsequent theoretical modeling efforts, Professor Witt's ongoing program has focused on crystal growth hardware requirements, operational hardware design and development, and characterization of the crystal product and process. New infrared equipment has been developed for materials characterization and monitoring the crystal growth process. In addition, new communication systems and interfaces have been developed to provide scientists from around the country with access to both his software and hardware systems.

Professor Witt's crystal growth hardware is designed and used to both explore the potential of space experiments and processing, and to provide a basis for optimizing crystal growth operations on earth. The benefits of even limited experimentation in space and theoretical mathematical modeling efforts to crystal growth technology development have been and continue to be substantial. Clearly, the primary impact of space experimentation will be a significant enhancement of crystal processing capabilities on earth. However, the possibilities for processing in space cannot be ignored, but should not constitute the major driving force for experimentation in space.

Other NASA sponsored research programs under the direction of Professor Julian Szekely and Dr. Yuh Shiohara have advanced our understanding of electromagnetically driven flows, undercooling, and recalescence in levitated metal droplets. The potential significance of this work lies in the possible development of novel materials structures through undercooling induced rapid solidification and innovative electromagnetic stirring systems with a broad range of metals and materials processing applications.

While Professor Szekely's studies of electromagnetic levitation of metal droplets were originally started as a support service function for undercooling and rapid solidification studies of levitated liquid metal droplets, it now serves as a new research tool in fundamental studies of the viscosity of undercooled liquid metals and the analysis of the structure of liquids. Key by-products of the levitation studies are a better understanding of the principles and practise of electromagnetic stirring which influences basic metal furnace design, electromagnetic casting and shaping systems, plus magnetic damping of convective flows.

Dr. Shiohara's research program in deep undercooling and rapid solidification of levitated liquid metal droplets has included a shuttle flight experiment aboard Columbia in January of 1986. This ongoing study provides access to detailed

knowledge of solidification mechanisms which are needed to establish processing parameters required for controlling the subsequent microstructure and properties of rapidly solidified materials. The advantage of this levitated metal droplet approach is the ability to directly observe a stationary droplet during solidification without the constraints and limitations of a physical container vessel. The ultimate goal is to achieve hypercooling of a droplet such that upon solidification, the released heat of fusion is insufficient to return the undercooled droplet to the liquid state. Such a process would produce a completely homogeneous solid droplet (roughly 1 cubic cm) with no microsegregation. Knowledge gained from these undercooling induced rapid solidification studies is applicable to the control of both normal and rapid solidification processes.

Note: Complete annual reports on all of the past and current NASA-sponsored block grant and specific contract research programs are available either from NASA or the Materials Processing Center.

MATERIALS PROCESSING CENTER INTERACTION WITH INDUSTRY

MIT is first and foremost an academic institution, with education and students as its primary products. This educational process is supported and continually enhanced by the research process in the pursuit of new knowledge at the frontiers of technology. This new scientific knowledge, and technology, generated by ongoing research programs, are transferred to industry via both the graduation of students, and also direct interaction with industry. America's current and future productivity, competitiveness, technological leadership, and economic well-being are directly dependent upon this interdependent education, research, and technology transfer process. The Materials Processing Center looks to industry both for the practical guidance necessary to maintain relevance in its research programs and as a collaborative outlet for its research results. The Center maintains its intellectual and research integrity by focusing its attention on the fundamentals of the materials processing science base required by industry to create and commercialize new materials and materials processing technologies, as well as enhance the properties and performance of existing materials and processes.

The Center takes direction from and interacts with industry through such organizations as its Industrial Advisory Board, Research Consortia, Industry Collegium, and formal visits, meetings, seminars, symposia, and conferences.

INDUSTRIAL ADVISORY BOARD

It was recognized from the very beginning, that the success of the Center would depend upon its ability to interact effectively with industry. To accomplish this goal, the Center established its Industrial Advisory Board which first met at the inauguration of the Center. This 26 member Board (Table 1) meets each spring to review the ongoing research programs and policies of the Center, and actively promotes direct interaction with industry. The Director of NASA's microgravity Science and Applications Division has been a member of this Board since its establishment.

MATERIALS PROCESSING CENTER INDUSTRY COLLEGIUM

The Center greatly expanded the scope of its direct interaction with industry with the initiation of the Industry Collegium in 1981. The Collegium brings together people from industry, government and MIT to work as partners in promoting innovative materials processing research and development. The associations made in these groups have led to an excellent interchange of ideas, information, and technology. There are currently 65 Collegium member companies, Table 2, and the long term goal is to extend membership to 100 companies. The Collegium operates in full cooperation with MIT's Industrial Liaison Program, which currently has more than 300 member companies worldwide.

Collegium services include frequent symposia held at MIT, each covering an area of ongoing research in materials processing. The major benefits of these symposia to industrial, academic, and government personnel are the timely dissemination of research results and the ensuing exchanges between speakers, center staff, and attending Industry Collegium representatives. Symposia give corporate members an opportunity to explore current research and its potential applications, suggest new directions for future research, and lay the groundwork for future participation in collaborative research programs. These symposia also provide opportunities for graduate students to become acquainted with representatives from industry and vice versa. Over the last two years, eight Industry Collegium symposia, Table 3, have been held and were attended by a total of nearly 700 participants.

The Collegium also publishes an Industry Collegium Report through which all published and unpublished papers, reports and theses by Center faculty, staff, and students are made available to Collegium members. In addition, the Collegium hosts numerous short visits and tours of MPC facilities by representatives of member companies and arranges extended visits, a month to a year in duration, by member company representatives interested in direct participation in MPC research and

Senator KERRY. Dr. Solomon.

STATEMENT OF DR. SEAN SOLOMON, SPACE SCIENCE WORKING GROUP, ASSOCIATION OF AMERICAN UNIVERSITIES, PROFESSOR OF GEOPHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. SOLOMON. Mr. Chairman, members of the committee staff: I also thank you for this opportunity to come before you.

You might get the impression from the affiliations of the panelists here that the university space science community comes only from Cambridge, Massachusetts. I am here also representing the Space Science Working Group of the Association of American Universities and the National Association of State Universities and Land Grant Colleges, two groups which together represent the majority of the major research universities in this nation.

I would like to talk to you briefly about the health of space science, particularly at universities, and about our perceptions on the Space Science Working Group of what NASA is trying to achieve with its proposed fiscal year 1989 budget for space science and applications.

NASA and many other groups have described space sciences in this country as in a state of crisis, a word that is almost becoming a cliche, but not because it is not true. This audience needs hardly to be reminded of the fact that in the sixties and seventies this nation was a leader in inventing whole new areas of space science. In contrast, this decade has seen the growth of vigorous programs by many other nations.

Other witnesses have mentioned the state of astrophysics and of earth science, in which many other nations and groups of nations are now competing, and in some areas leading, the efforts of this country.

My own field of planetary sciences is in a rather sorry state. This nation has not launched a planetary science mission in ten years. During that time, we have seen very vigorous efforts by other groups. We saw the first spacecraft missions to a comet, the Comet Halley, two years ago. Five different spacecraft, from the Soviet Union, from Japan, and from the European Space Agency, visited Comet Halley. There were no spacecraft from this country.

The Soviet Union has undertaken a very vigorous program of exploration of Venus in the last few years and has announced a very challenging series of missions to Mars, beginning with two quite technologically ambitious missions to be launched later this year.

According to Aviation Week and Space Technology, the Soviet Union is now even contemplating missions to the outer solar system, where previously the United States had been the sole player.

The decline in the health of space sciences can be measured in many ways beyond the absence of new launches, particularly at our universities. Universities, of course, as many have already mentioned here this morning, are a source of new ideas, new theories, new concepts for instruments and, most importantly, new scientists.

The universities are the training ground for the next generation of space scientists. In my view, one of the biggest tragedies of our present gap in the conception and launch of new missions since the Challenger accident is the loss of potential new blood for the space sciences, the future leaders of our next generation of missions.

As partial testimony to that, I can see a number of my space science colleagues in the audience. They are easy to recognize by their grey hair.

At my own institution, MIT, there is a center for space research that has had an extensive record of developing new instruments to address challenging problems in astrophysics and in space plasma physics. At its heyday, the center operated with a staff of managers, engineers and technicians that numbered near 80. That staff has since been reduced steadily with the decline in new oppportunities and funding so that it now numbers five.

Many other university groups are simply no longer able to respond to new opportunities in the space sciences.

What little is left at the universities is the base upon which we must build for future missions. Any further decline simply will put us out of business, will reduce us to a position where as a Nation we have to start from scratch.

Mr. Chairman, the space science working group, in prior testimony to this committee and to other committees in Congress, identified four major areas that NASA and this nation should address if we are going to return to a position of leadership and preeminence in space.

Briefly, they were to assure that science has access to space, to attend to the health of the space science infrastructure, to provide for new technologies and to provide for new science.

Problems in each of these areas has contributed to the weakened state of space science, particularly at the universities, for the last several years. The situation was, of course, exacerbated by the Challenger accident.

The SSWG believes that each of these issues is well addressed in the fiscal year 1989 NASA budget that is before your committee.

My time is about up and I cannot elaborate, but let me——

Senator KERRY. Well, take a minute. That is all right.

Dr. SOLOMON. Let me mention in each of these areas where we think NASA is proposing to take a major step toward attending to each of these concerns.

We are all victims of the decision made in the 1970's to concentrate on one launch system for all of space missions. The SSWG is very pleased to see the OSSA plan that now provides for a balance between space shuttle and expendable launch vehicles, and in particular for a new series of launches of moderate size missions of the sort that can provide for a rapid turn-around and that can respond to new scientific needs and opportunities.

There have also been some responses to the question of the state of the space science infrastructure at universities. Increases are targeted for several that should provide at least a first step toward restoring health to the university research community.

In the areas of new technology, we are pleased to see that moneys are in the NASA budget for the development of critical elements of ambitious programs to be undertaken in the near future: In the earth sciences, the Earth Observing System; in the planetary sciences, the new generation of spacecraft to the outer solar system.

We are pleased as well to see that new science plays a very important role in the NASA budget. There are resources to plan for new opportunities in microgravity science and in the life sciences, to build toward a centrifuge capability for understanding human physiology at low g, and for starting an initiative in long duration human space flight.

And last on my list, but by no means least, is the new start for the advanced X-ray astrophysics facility. It has already been mentioned that the field of X-ray astrophysics was born in Massachusetts.

X-ray astrophysics, which can only be done from space, is ;now a competitive field with observatio now being carried on by many other nations. AXAF, as you will hear from Dr. Tanenbaum, is a major step over all other existing and planned missions. It is a mission in which Massachusetts institutions play a very healthy role, and it is one that has been called for as a highest priority objective from the astrophysics community for nearly a decade.

The SSWG strongly support, this mission in its own right and as an example of the kind of challenging missions and enterprises that NASA should be undertaking to conduct a program of vision and vitality in the mid-1990's. Thank you.

[The statement follows:]

STATEMENT OF SEAN C. SOLOMON, PROFESSOR OF GEOPHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Mr. Chairman, Members of the Subcommittee, thank you for this opportunity to testify on the subject of NASA's space and Earth sciences program. My name is Sean Solomon, and I am Professor of Geophysics at the Massachusetts Institute of Technology and Chairman of the Space Science Working Group (SSWG) of the Association of American Universities. I testify today on behalf of the Association of American Universities and the National Association of State Universities and Land-Grant Colleges, whose members represent most of the major research universities in the United States.

THE PRESENT CRISIS

For many years the United States led the world in the space sciences. Our achievements provided a highly visible demonstration of this nation's scientific and technological prowess. In the last few years, however, and particularly since the Challenger accident, this lead has eroded. In some fields of space science this country is in danger of becoming a bystander.

The last American planetary mission launch was ten years ago. The Soviet Union, meanwhile, has pursued a vigorous program of exploration of Venus and has announced an ambitious and technologically challenging series of missions to Mars. Two years ago Comet Halley was visited by probes from the Soviet Union, Europe, and Japan, but none from this country. In the Earth sciences, France and the Soviet Union are distributing land remote sensing data superior in resolution to that obtained with U.S. civil satellites. In X-ray astronomy, West Germany, the Soviet Union and Japan contributed to critical spacecraft observations of X-rays from supernova 1987a, but unfortunately the U.S. had no operating capability to make these pioneering measurements.

The decline in the health of U.S. space science can be measured in ways beyond the hiatus in the launching of new missions. As research and analysis budgets for the space sciences have lost ground to inflation, research groups have found it increasingly difficult to remain viable. This is particularly true at the universities, which have traditionally provided the backbone for space science research in this country. Universities are a major source of new scientific theories and new ideas for spacecraft instruments. At least equally importantly, universities are the principal source of new scientific talent, through the training of graduate students and postdoctoral researchers. The declining opportunities in the space sciences have posed serious obstacles to attracting and retaining the best young scientific minds. As a result, the generation of young space scientists who will conceive and carry out the next set of scientific missions is dangerously underpopulated.

In its testimony to Congress last year the SSWG maintained that this nation must take deliberate action if we are to return U.S. space science to a position of preeminence. The SSWG presented four overarching issues that must be addressed to resolve the present crisis: (1) frequent and assured access to space for scientific exploration, (2) the vitality of the space science infrastructure, particularly at universities, (3) the timely development of advanced technologies, and (4) the continuing pursuit of new science.

We are pleased to see that the proposed FY 1989 NASA budget contains provisions to address each of these issues.

Roentgen Satellite (ROSAT) and initiates funding for a Titan IV for a planetary mission and a Titan III for Mars Observer or a Tracking and Data Relay Satellite. The budget also provides funding to initiate competitive procurement of intermediate-size boosters for the Global Geospace Science missions and of Scout-class ELVs slated to be launched at a rate of two per year as part of the Explorer program starting in FY 1991. The planned sequence of frequent, moderate size, Scout-class missions is particularly welcome, because it will provide many opportunities for new instruments, focused studies, and rapid responses to new phenomena. The Antarctic ozone hole and supernova 1987a are particularly vivid recent examples of scientifically compelling new phenomena that call for critical experiments to be carried out from space with a minimum of delay.

The principal NASA support for most university space scientists comes from the Research and Analysis (R & A) programs. As noted earlier, level or declining budgets for these programs in recent years have led to a substantial erosion in the ability of the space science community to conduct research and, at the universities, to attract graduate students and new scientists to the field. We are therefore pleased to note that the proposed FY 1989 NASA budget contains some increase in funding for R & A. Much of this increase, however, is designated for science-related facilities or for technology development for future missions. While the need for funding in these areas is genuine, the net increase in R & A funds available for space science research at the universities will be small. It is critical that the R & A programs show real growth in the FY 1990 NASA budget.

The development of advanced technologies provides the critical new instrumentation for the efficient planning and execution of new missions. New technologies, of course, also contribute to the nation's technological competitiveness. The proposed FY 1989 NASA budget includes significant development funds for the planned planetary missions to volatile-rich objects in the outer solar system, including a comet rendezvous and a Saturn orbiter with a Titan atmospheric entry probe, and for the Earth Observing System, a future cornerstone of NASA efforts in the area of Earth remote sensing. Timely development of long-lead instrumentation and spacecraft components will permit these missions to be brought forward as new start candidates in the near future. The funds requested to support agency planning for further exploration of the Moon and Mars are important to assure that well-formulated scientific questions will be among the objectives of these initiatives.

The proposed FY 1989 NASA budget contains support for several key areas of new science. Initiation of a set of facilities for materials science and basic physics and chemistry in a microgravity environment on the space station, development of the centrifuge for life science studies, and planning for the new programs in space

biology and in extended duration crew operations are all welcome components of the FY 1989 program. An exciting element of new space science is the Advanced X-ray Astrophysics Facility (AXAF).

The SSWG strongly endorses the proposed FY 1989 new start for AXAF. A new start in the budget demonstrates the nation's renewed ability to undertake challenging and pioneering space initiatives and to plan for an orderly series of space science missions for the mid 1990s. The new start for AXAF, in particular, is the culmination of a nearly decade-long effort to bring forward the recommendation of the National Academy of Sciences (NAS) Astronomy Survey Committee Report on "Astronomy and Astrophysics for the 1980s," in which a new start for AXAF was the highest priority objective for astronomy and astrophysics. AXAF will revolutionize our understanding of many of the most fundamental questions dealing with the origin and evolution of the universe by virtue of the hundred-fold increase in sensitivity and thousand-fold increase in spectroscopic capability over any previous or planned X-ray mission. X-ray astronomy is a field that was initiated by U.S. investigators but one which lately has been dominated by the successful space science programs of Japan, Europe, and the Soviet Union. With AXAF, U.S. leadership in this important field of astrophysics will be finally restored.

SUMMARY

With the proposed FY 1989 budget, NASA has taken a significant first step in implementing a long-term plan that will return this nation's program in space science to one of vision and vitality. The plan is responsive to the recommendations of NASA and NAS scientific advisory committees. The FY 1989 budget is carefully crafted to achieve a balance among support for ongoing programs, diversification of the launch vehicle fleet for space science missions, increased support for advanced technology development and for research and analysis, and new initiatives in microgravity and life science and in X-ray astrophysics. With this budget NASA has recognized the ongoing crisis in the space sciences and has set out on the road toward restoring U.S. leadership in space.

Thank you again for the opportunity to present this testimony. I would be pleased to answer any questions.

Senator KERRY. Dr. Solomon, thank you very much. Your statement is a very important one.

You are chairman of the space science working group. You represent a majority of the nation's research universities in that status, and you obviously make the statement that articulates very clearly the nature of the crisis, as you said. And it is an overworked word, but I think it is applicable.

You talk about the need to not only have access to space and to proceed on some of these projects that you have described, but also to revitalize the infrastructure of our universities.

And I wonder if it is premature for us in some ways to be, while not certainly premature, to dream about and have as an ultimate goal, is it premature to really start the ball rolling in some of the more adventuresome programs, such as the Mars mission and so forth, when that infrastructure really is not necessarily there?

And should the focus first be on infrastructure to a much greater degree than I think it is? Are we reaching too far?

Dr. SOLOMON. That certainly is a legitimate question. Of course, in the space sciences there is an entire spectrum of projects that can be undertaken, ranging from small scale projects that a university group can operate in its entirety up to the kind of very ambitious, long-lead exploration projects of the sort that you have just cited.

There was a time in the space science history when there were a number of opportunities for universities to run whole missions themselves. MIT operated a mission called the small astronomy satellite that was conceived and built entirely in-house, and for which all mission operations were conducted from the university. Graduate students could actually sit down and help design and build instruments and could be involved firsthand with data acquisition right from the spacecraft.

That is one of the kind of opportunities that we need to retain.

At the same time, I do not think it is too early to begin at least the planning for the long lead efforts. I think the Pathfinder program is evidence that NASA recognizes the rather large step that they must take if they are going to undertake piloted missions outside of earth orbit, and that the technology base as part of the infrastructure upon which to plan such an effort may not yet be adequate. They have to put more resources into that technology and that science base before making those bold steps.

Senator KERRY. Are the grant programs that we have in NASA, the graduate student research program in space science and so forth, adequate to attract the students and build the infrastructure, or do we need to do more?

Dr. SOLOMON. We need to do several things more. Graduate students nowadays are very, very bright, and they can see where different fields are heading. It is certainly an important step to make sure that the fellowship programs and the research and analysis grant programs are sufficiently healthy so that when good students are attracted into the space sciences there is support for them to develop and to concentrate on that field.

But more than that, they have to perceive that there is a real opportunity. They have to perceive that there are careers in the space sciences that are worthy of their attention and that the resources are there to support them in graduate school to train toward that goal.

Unless we do that, these bright students are going to see the handwriting on the wall and they are going to go into some other challenging field. And that is an irreversible decision. We will lose that generation of young scientists.

I am very eager to hear from some of the students we have testifying. I see them as part of the future of space sciences, and I hope we can continue to keep them excited and give them something to do that will convince them that this is a field in which they might want to devote their lifetime.

Senator KERRY. So it is fair to say that, given the budget choices we face this year in the space program, that an integral part of people's perceptions about the future and the ability to be able to sustain that pipeline for researchers and scientists for the future will depend on our own commitment within Congress?

Dr. SOLOMON. Exactly. It will depend on having a sufficient diversity of opportunity built into the future so that the bright students can see themselves as part of that future.

Senator KERRY. A last question. Are the demographics working against us with respect to that? Do we have to look to more foreign students in order to meet that demand?

Dr. SOLOMON. You are talking about a trend that has been fairly common in the technological fields in general, and the answer may be partly yes, because a larger and larger fraction of our students have been attracted, to fields outside of the sciences.

The population of technologically oriented students from this country, however, is still quite strong. We certainly see that at MIT in the engineering fields, if a little bit less so in the space sciences right now.

If we have a program of vision and if we have a program in which there is a long term plan that has sufficient ability and resources so that students can see that there will be exciting things to do in the 1990's, the students are there and we can draw them back.

There will be some element of foreign student participation, and I think that is healthy. But a lot of our students would like to go in directions of scientific and technological excitement as well.

Senator KERRY. Thank you, doctor, very, very much. We appreciate it.

Dr. Akin.

STATEMENT OF DR. DAVID L. AKIN, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Dr. AKIN. My name is Dave Akin. I am from the Department of Aeronautics and Astronautics at MIT, and I am very happy to be the token engineer up among the scientists to tell you about, not so much space science in and of itself, but some new capabilities we have that enhance all space operations, including space science, and that is specifically robotics and automation.

If I could have the first slide, please, I am going to talk real fast and flip through a lot of viewgraphs. You can see I was trained at NASA.

[Slide shown]

Dr. AKIN. This is what people think of when we talk about space robotics. It is something with arms that actually goes out and performs a task, and indeed it is one facet of robotics and automation technology for space that is very important when you talk about trying to understand what you can get with robotics, what unique capabilities robotics can give a space program.

You have to start off at the very basics, and the basics, as shown on the next viewgraph, is what can humans do.

This is a project done in my laboratory at MIT, looking at the productivity of humans in a simulated weightless environment (that we get under water) assembling space structures. And this led to the program with the next slide where we actually managed to build and fly an experiment that was designed to correlate all of the data we had gained under water with actual space flight experience.

Let me reiterate something Len Fisk said earlier this morning: A shuttle flight experiment is an extremely valuable experience for students. In the course of the 27 months from program award until the time we received the data back from the flight the hardware was built in our laboratory, largely by undergraduates. The testing phases of space flight qualification formed the basis for many of our undergraduate project laboratories. The great data that we got back from Mary Cleave and her crew mates on flight 61B formed the basis of masters theses and doctoral theses, and the students who wrote these thesis were there in our laboratory when the project started. They stayed, got the data, wrote the theses based on the flight data. It was a very unique experience, and it is very important that we try to enhance and get more of these opportunities to more schools across the country.

So humans are very productive in space, and we wanted to set out to see how productive we could be, and the next picture shows the same structure being built by a robot that we have developed in the laboratory. Let me say that the slides you are going to see are out of my laboratory at MIT, because that is what I happen to have on hand. You have to look at these images and multiply them by the research going on in NASA laboratories, in other universities and in industry across the country.

But I think these are representative of the types of technologies that you will be seeing in the future, and the types of capabilities that we can come to depend upon. We have assembled this space structure, this tetrahedral truss structure that we flew in space, using a telerobot. That means that some aspects of the assembly are automated (the robot does it by itself), but some aspects are controlled by a human.

So in terms of assembling these structures, we do know that robotics is a viable technology.

In the next slide, we can see that it is not an either-or proposition. If there is only one thing I would like to leave you with today, it is that the people who say that we should either have a manned space program or we should have an unmanned space program are wrong. The most productive space program we can possibly have is a proper blend of humans and machines working together, each doing what they do best. This is a picture from some of our research.

Taken at the NASA Marshall Neutral Buoyancy Simulator, this picture shows a work site where the robot is working alongside the human assembling a space station truss structure.

The next slide shows how far you can actually go with this. In this case, the test subject in the pressure suit is playing dead, is pretending to be incapacitated. The robot has come over and grasped her and it will maneuver her back into the air lock of the space shuttle payload bay mockup.

So this shows that not only can they work together in nominal situations; we have actually demonstrated that robots can enhance the safety of a space work site by rescuing an incapacitated astronaut.

Now, robots are not only things with manipulator arms.

The next picture shows an underwater vehicle that is basically used for mobility, for moving things around. This is very similar to a vehicle called the orbital maneuvering vehicle that NASA is working on, that will be very important for the space station.

You can tell that if you wanted to turn over the control capabilities of this vehicle to an automated system, and you are flying in the close proximity of a very fragile space station truss, you have to have a lot of trust in the capabilities of your control system to not fly into anything or crash into the space station.

The types of tasks we are looking at with this include how you would do docking. Automated docking will be a very important procedure in the future. The Soviet Union has been using this ever since the beginning of their docking procedures. We have never done an automated docking. All of our procedures rely on manual control.

We also try to look for hybrids between human activities and these robotic activities.

In the next slide you will see what we call the concept of an astronaut support vehicle, using something along the lines of an orbital maneuvering vehicle to provide mobility for the astronaut in a manner similar to that by the Martin Marietta manned maneuvering unit, but in this case providing much more capability, giving the astronaut the capability conceptually to fly a day or so away from the space station, and then egress in a space suit, use the vehicle as a base to work from, and then travel in the vehicle back to the space station.

Now, what specifically, since we are talking about space science, can the technology of robotics and automation offer? The one thing that is very important to remember is that humans are very productive in space, but traditionally overworked. If you go back to the experience of Skylab, what you find is that the crew worked extremely hard, but they only turned in about a 40 hour week on their experiments.

The reason is that, in space, much more of your time is required in the process of living than on the ground.

This slide shows an application that has no hardware attached to it at all. It is an artificially intelligent computer program that is designed to be used by the astronauts on the space station to plan their own day.

The idea is that it would make them more productive, that it would eliminate the need for much of the large staff of people in mission control. The system can also tell them where to find things, and as Mary Cleave will tell you, that is not necessarily an easy thing on orbit.

The next slide shows you again our robot assembling structure, but I invite you to think of this as a robotic vehicle inside a laboratory module, for example. And this brings up a program of very high potential called telescience.

You could have a robot inside of a laboratory module operating crystal growth experiments, or any other sort of thing that you would want to do. As shown in the next slide, it would be controlled from the ground by the scientist who designed the experiments.

So that in other words, this is a way that tele-robotics and automation technology will enhance our capabilities on orbit, by bringing the effective intelligence of more people on orbit than we can afford to physically send up to the space station.

My last slide is basically a reiteration of the point I made earlier. The important thing to remember is that humans are extremely capable, as they have shown time and time again in the space program. Robotics are also extremely capable, and have particular applications that they are more useful for, especially in routine and repetitive tasks, than humans. The best way to get the most out of our space program is to combine the best talents of both into a working team.

Thank you.

[The statement follows:]

STATEMENT OF DR. DAVID L. AKIN, ASSOCIATE DIRECTOR, MIT SPACE SYSTEMS LABORATORY

I appreciate this opportunity to address the capabilities of automation and robotics technology to impact space science in the coming years and decades. This is an exciting field, and I hope I can communicate some of its excitement and potential in the limited time available.

I come into this discussion by multiple paths. The bulk of my current research at the Massachusetts Institute of Technology is concerned with space robotics, but my original contributions in this field were in space human factors. While my current work is developing technology capable of increasing the return of a scientist from a space flight experiment, I also was fortunate enough to be the Principal Investigator on the Experimental Assembly of Structures in EVA (EASE) program, which flew on Space Shuttle Atlantis in December, 1985. So, as you can see, I am representing both the technological development community and the experimental user's community here today.

In a discussion of automation and robotics in space, it is important to remember that robots have been in space as long as there has been a space program. To some extent, all satellites, probes, etc. are automated devices, performing their appointed tasks without regular interaction with humans on the ground. The key difference between the types of automation and robotics I will be talking about today, and the automation of "conventional" satellites, is the capability to perform physical actions ("robotics") and/or the capacity to modify its programming as necessary ("automation"). Researchers in this field are currently engaged in extending some of the unique capabilities of human beings to our robotic systems, to enable them to perform more of the tasks currently done by humans, either in space or from the ground.

So what can automation and robotics do? By way of answering this question, let me first speak only of the capabilities demonstrated in my research lab at MIT. Telerobotic devices can assemble space structures. Our Beam Assembly Teleoperator has assembled the same structure assembled by astronauts in space during STS 61-B in December of 1985. The same robotic device has demonstrated the capability to rescue an incapacitated astronaut and return him to the space shuttle airlock. We have had robotic devices, working both alone and in concert with people in space suits, assembling space station-type truss structures.

We have developed a robot capable of maneuvering itself around the space station, walking "hand" over "hand" along a truss structure. We have developed an artificial intelligence program which cooperates with space station crewpersons in arriving assignments for their daily tasks, trying to maximize the data return while giving the crew a real say in how they carry out their duties. Multiplied by the many other laboratories across the country, either at NASA or supported in whole or in part by NASA, you can see a great swell of robotic capabilities arriving to revolutionize space activities in the next decades.

How can robotics and automation technology improve the potential for space science? Let's look at the first (and last) U.S. space station: Skylab. We learned from this just how effective humans can be in the space environment, and specifically in the collection of scientific data on-orbit. The Skylab mission itself would have been a total failure without the crew to repair the damaged workshop, and to keep all of the components operating throughout the planned lifetime of the program. One of the things we learned from this program, however, is just how precious human time is in space. For the next planned U.S. space station to succeed as a source of scientific knowledge and innovation, we must maximize the capabilities of the limited crew on-board.

One way of doing this is to relieve the crew of as many mundane duties as possible, leaving them free to concentrate on the important experimental objectives. Looking at

Skylab data demonstrates that the crew, while working near or at the limits of human capacity day after day, only averaged the equivalent of a standard eight-hour day at their scientific experiments. The significant factor in this discrepancy is that more than twice the normal time was spent in the routine daily matters of living in orbit - fixing dinner, cleaning up, obtaining the greater daily requirement of exercise, keeping track of data, bookkeeping and routine paperwork. While robotics technology does not seem likely to eliminate the crew's need to exercise (although such a device would certainly have spin-offs in commercial markets on earth!), all of the other routine functions indicated can be eliminated or greatly reduced from crew requirements by clever applications of robotics and automation. Perhaps this will not give the crew any more time to perform experiments, but providing them with a more normal total daily workload will certainly maximize crew productivity over an extended mission.

Perhaps one of the most exciting aspects of robotics and automation, with a great potential to impact space science capabilities, is called telescience. This technology would take telepresence - that is, the remote control of devices with arms, and eyes, and other human sensors and actuators, of sufficient dexterity and resolution to give the remote operator a sense of physical presence at the worksite - and extend it into an orbiting laboratory. Scientists on the ground, through telerobotic devices, could operate their own experiments in orbit, change samples, perform minor repairs, collect data, analyze trends, and modify procedures and data collection in real time. This, too, would free up the crew actually present in space to perform those tasks not well suited to telerobotics, such as highly dexterous manual operations and flight control functions.

I have discussed what automation and robotics technologies are capable of today, and some extrapolation into the future. It is clear that these technologies are not bound by the slow evolutionary process of biological systems, and are advancing rapidly. Let me make a simple assertion: at some point in the future, robots will be more capable than human beings. This is a statement of fact; the only room for argument is on the question of when. Ten years? Probably not. One hundred years? Almost certainly. Somewhere in between? Most likely.

So what then? When robots become as capable as a human, do we then pull all humans out of space, and allow our robotic stand-ins to continue our exploration of the solar system and the universe? Frankly, this is a question which transcends the technological implications. It reaches directly to the core of politics, and policy, and philosophy. If a single engineer's opinion is of any value, then despite any quality of image, or amount of data, or subtlety of programming, I would philosophically (as a human chauvinist) assert that exploration is one of the last jobs which should be turned over to robots, as the curiosity and thirst for knowledge underlying the urge to explore is one of the finest attributes of being human. Let us instead spend our efforts getting humans out of mine shafts, and off of high steel construction sites. Robots should totally replace humans in the worst of human jobs, not the best.

If I leave you with a single point to remember, I would like it to be this one: *the most effective way to perform useful work in space, now and in the foreseeable future, is with a proper mixture of humans and machines each doing what they do best.* Although there are periodic discussions of whether NASA money would be better spent on unmanned scientific probes than on manned space flight, the worst mistake that can be made is to think of the two approaches as an either-or proposition. Indeed, they are complementary parts of a single approach which will maximize our scientific and technological return from space exploration and development.

Senator KERRY. Dr. Akin, you made the statement during your presentation that you thought the mix of robotics and man was important. Can you show us, why is the mix so important? Are there some missions where it could be purely robotics, or are you saying across the board there is a mix?

Dr. AKIN. Well, there are some missions that have to be robotic. A good example of a robot is the Viking lander on Mars. Prolonged activity in geostationary orbit, where most of the communications satellites are almost has to be robotic.

Senator KERRY. I was thinking more in terms of the orbital science.

Dr. AKIN. In terms of orbital science, again let me go back to geostationary orbit. It is a very important position for earth resources because you are over a single point on the earth. If you have activities that need to be interactive at that point, you cannot really use humans because the radiation environment is fierce. Telerobots would be a very good way to do this.

In terms of orbital science in the Space Station, you are just not going to be able to send up enough people to do everything you would like to do. You would like to have the experimenter on board with his or her experiment, but in a situation where you have hundreds of experiments and six crew members, that is not going to happen.

Telescience offers a way of transferring the expertise of the scientist into orbit, to enhance the return from the experiment.

Senator KERRY. Is the emphasis today in your field on automated systems, such as based upon artificial intelligence, or is it in the mechanical, the robotics?

Dr. AKIN. Those are really two parallel thrusts. There is a lot of work on what is called systems autonomy, adding artificial intelligence elements to systems to increase their capability, and to decrease the problems with failures.

There is also a lot of work being done in space robotics, in actually manipulating items, and performing physical work in space. The two are obviously interrelated, because the trend is to try to see how much autonomy, in terms of freedom from people, we can give our robotic devices.

Senator KERRY. Would you say that the civil space program continues to drive technology developments, or has that now shifted to defense and industry itself, to the Defense Department plus industry?

Dr. AKIN. Frankly, I am not really aware of very much that the Defense Department is doing with their space budget to enhance these technologies. I would say the primary driver in this field today is NASA.

Senator KERRY. Would you say that—I think you made a statement some time ago that the Japanese had caught up to us as to each of the disciplines and the Europeans were behind us in two or so. Has that changed?

Dr. AKIN. The Japanese are certainly at parity or ahead. I would say the Europeans are also at parity with us. They have a very ambitious program called Rotex that they hope to fly on the next German

Spacelab mission in, I think, 1990 or 1991. Right now we have the flight telerobotics servicer, which is a large operational program, but that would be a couple of years behind the German experiment.

Certainly we do not have much of a lead, if any at all, in this field.

Senator KERRY. A last question. Could you share with us the direct paybacks to the U.S. industrial and educational base from this little program you described?

Dr. AKIN. Well, there are the obvious paybacks, in that the research that NASA supports is directly supporting students in academia, and is supporting the development of expertise in industrial laboratories.

This is one field that I think has some real potential for the classic spinoffs back to earth industries. As I said in my written testimony, I think the important thing about robotics is not developing enough capability to take humans out of space; it is developing enough capability to take humans out of deep mine shafts and off of high steel girders.

The idea is that as robots become more capable, they should be able to, both on earth and in orbit, replace humans in the worst jobs, the dangerous jobs, not in the significant human jobs, such as exploration.

Senator KERRY. Thank you very, very much, Dr. Akin. We appreciate it.

Dr. Tananbaum, thank you.

STATEMENT OF DR. HARVEY TANANBAUM, SMITHSONIAN ASTROPHYSICAL OBSERVATORY

Dr. TANANBAUM. Good morning. I am pleased to be here to discuss the advanced X-ray astrophysics facility, or AXAF for short.

As we have heard, our space program has been through some difficult days. In response to the widespread call to reassert American leadership in space, NASA has proposed a forward looking program which the science community strongly endorses.

My field is X-ray astronomy, one of the first new areas of research made possible by the space program. Our observations must be carried out from space since X-rays are totally absorbed by the earth's atmosphere.

Observations with AXAF will show us how matter behaves under extreme physical conditions which cannot be reproduced on earth. X-rays produced in astrophysical laboratories, such as the surface of a neutron star or the environs of a black hole, will test the basic laws of physics, showing us how they stretch, bend, or perhaps even break.

Our colleagues in Japan, the Soviet Union, West Germany, and other European countries have recognized that X-ray astronomy is spectacular science. Since 1978, when the U.S. launched its last X-ray satellite, the Einstein observatory, other countries have flown six X-ray missions.

So, as we have already heard today, it was the Japanese Ginga and the Russian Mir which first detected X-rays from last year's once in a lifetime supernova explosion. Six more foreign missions are planned before we can launch AXAF in the mid-1990's, and that is based upon our starting AXAF now.

Compared to these other programs, AXAF will be a tremendous step forward. Its pictures will be ten times sharper. It will study objects 100 to 1,000 times fainter. The cost of the AXAF development, approximately one billion current year dollars, does represent a significant investment. While it is expensive to develop and orbit a high resolution X-ray telescope, we do expect a large number of astronomers and students to observe with AXAF and to carry out a vigorous mix of large and small research projects. Moreover, work on AXAF contributes to our technology base and our economic competitiveness through commercial adaptations of advanced X-ray optics and detectors.

Now, to further illustrate some of the AXAF science, I have brought along a short video with a few friends.

[Whereupon, a videotape recording was played:]

Narrators voice: If we had X-ray eyes, we would see the cosmos as a dynamic and violent place, ablaze with the remnants of exploded stars, alive with quasars, some brighter than a trillion suns, aglow with X-ray emissions, their origin as yet unknown.

When we study the motion of galaxies and the structure of clusters of galaxies, we must conclude that they are governed by the gravitational force of unknown sources referred to as "dark matter." Perhaps dark matter in the universe is made up of exotic particles conceived by recent grand unified theories—axions, monopoles, and superconducting cosmic strings.

Dr. Weinberg's voice: Now, how do you detect them? Well, it is very hard. They do not interact very strongly. They do not do the things that ordinary particles do. But one thing they do is produce gravity.

Every kind of particle contributes to the gravitational field, and it turns out that the very best tracer of the gravitational field within clusters of galaxies is the hot gas that produces X-rays.

So AXAF, in tracing out this hot gas and seeing where it is and how it is moving, is going to be able to tell us about the gravitational fields within galaxies and clusters of galaxies.

Narrators voice: Going forward with these important studies requires a new astronomical instrument with a power, sensitivity, and resolution that has not been available until AXAF. At the heart of AXAF is a nested set of grazing incidence mirrors that focus incoming X-rays onto four sets of focal plane detectors. Two of these detectors are modern versions of ones proven aboard the Einstein observatory. The other two use new technologies with exciting potential for X-ray astronomy.

Dr. Field's voice: The study which I chaired recommended as its number one priority the AXAF facility. The tests required have all been accomplished. The budget is well understood. The project can be done, and it will have an immediate payoff for all of science.

Dr. TANANBAUM. As a nation, we have embraced the goals of excellence in science and space research. AXAF embodies these goals. We are very excited about this mission. We are committed to its success.

What we really need now is your support. Thank you.

[The statement follows:]

STATEMENT OF DR. HARVEY TANANBAUM, HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS, CAMBRIDGE, MA

I am pleased to have this opportunity to discuss the Advanced X-ray Astrophysics Facility (AXAF). A new start for AXAF constitutes a major step forward in reasserting American leadership in space science. These have been difficult times for our space program, and in response NASA has now proposed a robust and forward-looking program. The science community strongly supports NASA's initiatives to reestablish U.S. preeminence in space, and we urge Congress to provide the required funding.

Space Science and Applications today encompasses a broad range of interests. My field, X-ray astronomy, was one of the first new areas of research made possible by the space program. Since cosmic X-rays are totally absorbed by the Earth's atmosphere, X-ray observations of stars and galaxies must be carried out from space. With rockets and balloons in the 1960's and then with satellites in the 1970's, X-ray astronomers discovered some of the most remarkable phenomena being studied today. Bright X-ray sources in our galaxy are found to be double star systems containing black holes or neutron stars which swallow matter lost from their companions. X-ray observations also reveal massive amounts of superhot gas filling the spaces between galaxies in clusters. For their pioneering work in X-ray astronomy, Riccardo Giacconi, Herbert Friedman, and Bruno Rossi were awarded the prestigous Wolf Prize in physics.

Modern astronomy, especially with observations from space, has revolutionized our view of the Universe. It has revealed a violent and explosive cosmos, previously unseen because many of the phenomena radiate at wavelengths invisible to the human eye. Immense forces heat gases and accelerate particles to produce powerful streams of X-rays. This leads us to study objects with exotic sounding names, such as neutron stars, black holes, supernova remnants, active galactic nuclei, and quasars. To understand the puzzling processes involved, we need AXAF.

X-ray studies with AXAF will allow us to probe the properties of matter under extreme conditions of density, temperature, pressure, gravity, and magnetic field. These extremes far exceed what we can produce in our earth-bound laboratories and thereby allow us to study the basic laws of physics to see how they extend, bend, or even break. The power of AXAF will enable us to make precise measurements of the energy output of all sorts of stars and galaxies. We will use these data to learn about such diverse phenomena as energy transport within stars, explosions of stars, the expansion of the Universe, and the distribution of the puzzling invisible (or dark) matter that seems to pervade much of the Universe. AXAF will have the power to detect X-ray emission from quasars, galaxies, and clusters of galaxies at the distant edges of the Universe. Even though X-rays travel at the speed of light, it still takes many billions of years for the X-rays from these objects to traverse the Universe and reach our telescopes. So what we can see with AXAF is how the Universe looked some 10 to 20 billion years ago.

X-ray observations with AXAF also will be relevant for a number of other fields including cosmology, plasma physics, and studies of elementary particles. The Superconducting Super Collider (SSC) has been proposed as a major scientific initiative in the U.S. A primary thrust of the SSC is to greatly extend the range of elementary particles that we can create and study in the laboratory. From such observations, physicists hope to be able to find new particles and forces which govern the broken fundamental symmetries which characterize our physical world. With AXAF observations, we will be able to measure the total mass and shape of individual galaxies and clusters of galaxies. We also expect to make global measurements of the expansion and mass content of the Universe. From this astronomical inventory process, we can narrow down the list of candidate dark matter particles to a very few, which will provide us with essential information on various symmetry theories. What all this means is that AXAF will determine the global role, on the scale of the Universe, played by the particles and forces discovered with the SSC.

Our colleagues in Japan, West Germany, the USSR, and other European nations have taken note of these scientific spectaculars. The last U.S. X-ray astronomy satellite - the Einstein Observatory, our first X-ray telescope - operated in space from 1978 to 1981. Since the Einstein launch, other countries have launched six X-ray satellites, with another six planned before AXAF can be launched in the mid 1990's. As a result, the Japanese and the Russian/European Consortium first detected X-rays from last year's, once-in-a-lifetime, supernova explosion in our neighboring galaxy, the Large Magellanic Cloud.

The better of the foreign missions flown to date and even those planned for the next several years will achieve a resolution and sensitivity comparable to or at best, slightly better than Einstein. On the other hand, AXAF represents an ambitious step forward. Compared to Einstein, AXAF will obtain pictures 10 times sharper and will study objects 100 to 1000 times fainter. These great improvements in capability arise from substantial technological advances in precisely shaping and smoothing the surfaces of the X-ray mirrors. With NASA and industry, we have already built a test mirror which demonstrates that the AXAF specifications can be met and therefore that the projected scientific advances can be achieved.

AXAF has been under study for a decade now by NASA, the science community, and industry. Detailed studies have been completed by two competing industrial teams. A preliminary set of science investigators and instruments has been chosen. The experiences from Einstein, Hubble Space Telescope, and Gamma-Ray Observatory are being applied, and issues involving on-orbit servicing and the nominal 15 year mission life have been addressed from the outset. In recognition of limited funding available in the first two years, the program is structured with a phased start emphasizing the X-ray mirror and science instruments at first. This approach has the further advantage of advancing the high technology, schedule-driving areas. As we proceed, the schedules can be adjusted, if necessary, before the higher cost phase of the program begins.

Senator KERRY. Thank you, doctor.

Doctor, what is the composition of the user community, universities and research centers? And how many states that would benefit from the AXAF program?

Dr. TANANBAUM. Probably the best way to address the future is to look at the not so recent past. The Einstein observatory flew from 1978 to early 1981, and in two and a half years it was used by several hundred scientists.

The data archive continues to be used. There are nearly 100 research institutions in the United States represented, in 32 or 33 states at this point in time. There are also 18 foreign countries, with some 75 or 80 institutions also represented among the users of the Einstein data.

AXAF is projected to operate in space for something like 15 years, and so I think we can fully anticipate a user community that numbers in excess of 1,000 spread all over the country and in fact all over the world.

Senator KERRY. And based upon your experience with the Einstein mission—I mean, you articulated this a little bit, but can you be more precise about what the level of scientific return could be from this?

Of course, a lot of it is unknown. But in terms of just quantifying it against other experiments that we are considering?

Dr. TANANBAUM. I think one should address it on both the level of the known and the unknown. In many ways, AXAF is a sure thing. We have done enough work with space astronomy and in particular X-ray astronomy that there are things out there that we know that we can detect and for which we can make certain very precise measurements.

We want to use AXAF to weigh galaxyies to see, how much mass they contain. We want to understand as we look farther and farther away at more distant objects, how galaxies and groups of galaxies looked early on in the universe. And by looking at those sorts of things, by doing precise measurements which we can define today, we can learn a tremendous amount about how the universe developed early on and how it came to look the way we see it today.

There are also very precise measurements we can make when we look at the remnants of a supernova explosion. We can actually study the chemistry, and by looking at the detailed energy content we can tell what made up the star that exploded. And so these measurements can test our theories of how stars evolved and what eventually goes wrong or occurs when they cannot support themselves and an explosion occurs.

Of course, there is the unknown, the things that we probably are not even well enough informed to ask about today. And when we start to make observations we are going to find surprises. We are going to get hints of things which are going to require successive observations, to look in greater detail and to follow up on what we call the serendipitoua nature of science.

But it is really not just luck. It is some intuition, some knowledge, and the building of the right device and using it in an intelligent way.

Senator KERRY. The last X-ray effort was in the 1960's?

Dr. TANANBAUM. Late 1970's.

Senator KERRY. Can it be said that this would be the demarcation point between our being the leader or not participating?

Dr. TANANBAUM. Yes, I am afraid that is the case. I wish it were not so black and white, in a sense. I have worked as an X-ray astronomer since I was a graduate student at MIT in the sixties. In the sixties and seventies we had a vigorous program and we always knew what our next program or two or three were going to be.

The fact of the matter is that we are looking at about a 15-year hiatus from the cessation of operations of Einstein until we can get AXAF up in the mid-nineties. 15 years is a long time to keep a group of scientists together, to be able to attract new talent, to get graduate students that are trained and interested in working in a field.

We have managed to do that so far. We have not been sitting idly by. We have used the time and the technology money that has been made available to make the best X-ray mirror that has ever been built. This gives us the confidence to know that we can make the mirrors that are at the core of the high performance on AXAF.

But we are at the point now where we have done all of the precursor development work that is reasonable to do. We are ready to go ahead with the program, and we need to simply take that step and proceed to build it.

The people that will be involved in building it are part of the potential user community. In the meantime, some of the other scientists will be making use of things like the Hubble space telescope, and they will find that when AXAF is up there they can complement their research by looking not only at the optical ultraviolet part of the output from an object, but also with AXAF at the X-ray output.

So the science community absolutely needs a commitment for going ahead with AXAF so they can plan their research and so we can do the things that we need to do to get AXAF built and operating in space.

Senator KERRY. Thank you very much, doctor. We appreciate it enormously.

Before we shift panels to our last panel, which are our students, I just wanted to ask each of you one question since we are running a little late and I must move on.

I asked Dr. Solomon this earlier and I would like the others of you to respond very, very quickly, and I think it is a good lead-in to our last panel. And that is the question of the available infrastructure -- students, facilities, and otherwise.

Are they there? What do we need? And if quickly each of you would just run down and touch on that, beginning with Dr. McCarthy. And if you feel it is not something you are versed in enough to address, just say so.

Dr. MCCARTHY. Just briefly, I think the answer would be similar to that which you just heard regarding AXAF. For the remote sensing of earth properties, we also have a community that is waiting for the next generation of satellite sensors.

And if those are delayed, we will lose the interest not only of that community, but certainly we will lose the ability to draw young people into this field, which I think scientists today in the field believe is the most exciting field one could be in.

And if we can no longer make the convincing case that there is a future in this field, then clearly we cannot attract the brightest young minds to the field.

Dr. KENNEY. In materials processing it is a little different. We have an industrial base that brings the technology along as well. In space processing it is a little more difficult because again the lack of access to space simply puts experiments on hold, and it is difficult to bring graduate students into it.

Graduate students that have committed to it find themselves looking, looking for alternatives and looking for ways of exploring their careers short of the microgravity component.

As far as students are concerned, in processing and in space processing, materials processing, we do not tend to have that much of a problem attracting students to it. As far as equipment is concerned, that is always a problem. In some cases we have some of the best equipment in the world and in some cases we have some of the worst in terms of age and just non-functionality.

So there is a multifaceted problem that needs to be addressed. I think you referred to it earlier. You have to pay attention to your infrastructure and your foundation. Otherwise, your head-long race to be number one is going to—you will get there and you will have the best and brightest in science, but your technology is lacking and you will have nothing with which to convert it into a commercial product.

Dr. SOLOMON. Do I get another chance?

Senator KERRY. If you want to amplify, please do.

Dr. SOLOMON. To me the answer is that one needs a balance among many elements. We need a long term plan with some sufficient stability so that young people can see a future in space sciences.

Senator KERRY. Is the Paine Commission an adequate plan?

Dr. SOLOMON. The Paine Commission has come up with a number of very visionary ideas, most of which are very long term programs. And certainly a part of any space science program should be an enunciation of ambitious goals which can provide a basis for planning and for development.

But that is not enough. There needs to be attention to small things as well as big things. There has to be sufficient opportunity to launch small missions, to launch modest experiments that can have a rapid development time, comparable to the lifetime of a graduate student in grad school, or that can respond to a new supernova or to a hole in the ozone layer over the Antarctic.

There need to be enough resources devoted to the launch vehicle fleet so that if a Titan or a Delta suddenly develops some fatal flaw, there are still ways to launch missions on the shuttle or some other expendable launch vehicle.

And finally, as part of the long term plan, resources have to be put into developing technology so that when a new mission comes along, we have invested sufficiently in the technology so that we are not going to be surprised, so that we are not victimized by cost overruns, by delays, and by having to grapple with problems that should have been solved very early in the development stage.

To get the best young people into the field, to assure them that this will remain an exciting area for decades, one has to pay attention to all of these issues.

Dr. AKIN. In my field, I am lucky that I can draw from two large, enthusiastic groups—the space engineering students who want to be designing and building and, frankly, flying the next generation super-shuttles and who want to form the crew of the Mars mission; and at the same time, a very large and enthusiastic group of students that are really excited about artificial intelligence and about applications of computers. I have to turn away four or five students for every one that I can bring into the laboratory. The body of interest in this aspect of technology is vast, and there is no way that we can do justice to all of the students who want to get into it.

In terms of facilities, obviously that is a large problem. All of the hardware you saw in my slides was built on World War Two vintage machines. We have computer applications that in industry would be run on work stations, that we run on Macintoshes and IBM PC's because that is what we can afford.

You always need more than you have—while I hear that being poor is a virtue, we are a little more virtuous than we would like to be.

Dr. TANANBAUM. I have the advantage by being at the end of the table. Of course, I have forgotten exactly what the question was.

Senator KERRY. That is not an advantage. Having said that, we are going to move on.

Dr. TANANBAUM. I would like to second what my co-panelists have said, and I would like to share the following sentiment. I am really tired of apologizing for our space program. I think we know what we want to do, by and large, and we really know how to do it, and we are ready to do it.

If we get some of the things that are on the ground up into space and if we go ahead with some of the projects that we have been talking about today, then we will have a program that will serve this nation very well, in all the ways that have been discussed.

And I would like to think that the most important thing for moving ahead is to provide the funding and to show that the commitment to moving ahead with the program is real.

Senator KERRY. Well, I appreciate that.

I appreciate your comment. I might have something more to say about that at the end of the hearing.

We do have three students who have been waiting patiently. I want to thank this panel very, very much.

Ladies and gentlemen, we have three students: Rashawn Seams, who is an eighth grader at the Timilty Middle School in Roxbury. He completed a full year space science course last year and he has attended the Museum's Summer Space Camp. He is a talented performer and a number of his classmates are here.

If you could come up to the front podium.

And Pamela Gay, who is a ninth grader, a California native, who can remember the shuttle having passed over her own school. She wants to fly. She is ready, as you can see. And she has got Mars on her mind and wants to make that mission.

And Mark Gannon is a student whose contact with Project STAR, which is a partially NSF-funded program, has helped him to focus on his other studies.

We are delighted to welcome these three students here and look forward eagerly to their testimony.

Pamela, we are going to begin with you.

Why don't you describe what that medallion is around your neck? We know you did not get it from your last space flight.

STATEMENT OF PAMELA GAY, PROJECT STAR STUDENT, ABBOT MIDDLE SCHOOL, WESTFORD, MA

Ms. GAY. When I attended the U.S. space camp, I was awarded the outstanding trainee award. It is the highest award offered to the students who attend there, and I am told I was the first girl to win it.

What it means is that I was able to command my unit without being overbearing—making them feel like I was the ultimate thing. We were all a team and it was part of my job to make sure we worked as a team. I was able to get along with people and I was able to remember the stuff we were taught, and not just walk around.

My name is Pamela Gay and I am an eighth grader at Abbot Middle School in Westford, Massachusetts. I am involved in the Young Astronauts Program, where I am currently working on Project STAR. I am a member of my school's student council, school band, the newspaper staff, and I have a part in the school play.

I am planning to attend the U.S. Space Academy in May of this year. And after high school, I hope to attend the U.S. Air Force Academy and train as a pilot and get a degree in aerospace, and eventually I want to go on the Mars mission.

As we enter the twenty-first century, space is becoming more and more a part of our everyday lives. Today's students do not only need to know about the world around them, but they need to know about the universe if they hope to become the leaders of tomorrow.

The advances in space medicine, industry, satellite communications, and a multitude of other such miracles affect our daily lives in more ways than most of us realize.

Currently we find ourselves faced with a shortage of people willing to enter the field of science. This I feel is due to a lack of knowledge about how exciting the universe beyond our own humble planet truly is. Through an improved science curriculum in such fields as

astrophysics, aerospace, and astronomy, I believe this could be remedied by teaching not only what is known, but how scientists make the discoveries, using experiments. It can be proven that science is fun. This is the intent of Project STAR. This course uses labs to relate science and math to the universe around us. Project STAR gives us information in such a way that you do not realize you are learning, for the way something is taught is the key to learning.

We just do not need more emphasis within the schools. Outside enrichment programs are also needed. Programs such as Young Astronauts provide kids interested in space an ongoing experience to work on projects they would not otherwise be able to do, while in the process allowing them to pass their experiences on to others. Places such as U.S. space camps and Challenger centers also provide excellent programs and facilities for those interested in space.

While attending the U.S. space camp in Huntsville, Alabama, in May of 1987, I was able to try out simulators similar to those used by real astronauts. It was fun to not only experience things like 3g, but also in the process to watch the adults around you turn green. We also found ourselves wanting to stay up late so that we could do extra work on the programs and projects we were challenged to perform. This was because the things were presented as a game and we found ourselves wanting to complete them so that we could win the awards that were offered. While attending, I also had the chance to be commander of the first all-girls unit, and it was because of the people in my unit that I won the outstanding trainee award.

As we enter a new age of technology, we must decide where we want to go from here. I feel America needs an active space program if we hope to keep up with the rest of the world. We need an earth to orbit vehicle, whether it be in the form of space shuttle or heavy lift vehicle, to unlock the door to the building of the Space Station. Once we have an operational Space Station, the possibilities become almost unlimited. Should we choose to go to Mars or stay home, the Space Station will provide us with a base of research, to refuel ships, perform research, and learn more about the vast universe which we call home.

For now, all I can do is study and use my imagination to take me to space. I ask you to please continue to fund these programs and ones like them, so that when the time comes for my generation to reach for the stars we will be able to do more than just dream.

Thank you for letting me address you today.

Senator KERRY. Rashawn, why do you not go next, and wherever you are more comfortable. You can either sit at the table or go up to the podium, whatever you would like. Thank you.

STATEMENT OF RASHAWN SEAMS, JAMES TIMILTY MIDDLE SCHOOL, ROXBURY, MA

Mr. SEAMS. Good morning, Senator Kerry, ladies and gentlemen of the Science, Technology and Space Subcommittee, and other distinguished guests. I am extremely honored to have been asked to share my experiences as a participant in the Timilty Middle School's Young Astronaut program.

The Timilty is a Boston public school located in historic John Elliot Square in Roxbury. I am at present an eighth grade student at the Timilty. I was privileged to be among the first students who piloted the first space program at the Timilty during the 1986-1987 school year.

Hearing of a space program that I could be involved with was one of the most exciting things to have ever happened to me, especially since at that time I had planned to be the first teen-aged astronaut.

Mr. SEAMS. My first challenge was to design and build a futuristic sport game playable in space. I was part of the team that built a game I designed called Basketreat, that was entered in a statewide contest at the Boston Science Museum. The game won special recognition for the most original and most scientifically accurate sport.

Another intriguing project was to construct and actually launch a small scale model rocket. An extremely hair-raising excitement for me was wearing a genuine Apollo space test mission suit, being interviewed, and having my picture taken by Time Magazine.

I enjoyed working with Loren Foley, the representative from the Science Museum's school space program, along with other museum personnel. And I especially liked the exhibition they sponsored showing the model stages of the NASA space program from the Explorer satellite to the late Challenger.

I learned to do life-like experiments previously done by astronauts in space flight testing materials in a vacuumed and chemically gas environment. I was involved with lots of research, both written and observational.

I was privileged to have seen several science and space-related movies. A portion of time was spent on a project reviewing Sally Ride's book about her experiences as the first female astronaut.

One unique educational experience I had was my trip to the Omni Theater at the Museum of Science. It was really thrilling. At that time, I thought it was probably the closest thing to an actual space mission.

These space programs stimulated my mind to such a degree that it became fairly easy for me to make career choices. Information from NASA's space center in Washington was in my mailbox practically every week. I had a deep concentration of math and science, which earned me an A average in both subjects.

My 1986-1987 school science project was to design and construct a potentially livable space colony. The project won me the recognition of best of fair in my division and the chance to compete at the Boston city-wide science fair.

I always go to school on Saturday because my school is a Project Promise school and Saturday is a school day at the Timilty. Recently, I have enrolled in the Saturday science lab program at Mass Prep, which is short for the Massachusetts Pre-Engineering Program for Minority Students. My involvement enabled me to explore a different way of learning, especially through hands-on experiences in science.

I found myself hoping the space program at the Timilty would never end. Well, for me my adventures in space did not end. Through another school program called Promising Pals, I was honored to have

Loren Foley as my pen pal. My correspondence resulted in my being awarded a full scholarship to the Museum's summer space camp for two weeks.

I was ecstatic. The space program at the Timilty was of great value to me and I am sure for my school. The unique experience I received was one I will always remember. To the person or persons who made it possible for me to be a part of the innovative program, I am deeply appreciative.

I look forward to pursuing my interest in space as I go on to high school and college.

Thank you.

Senator KERRY. Mark. Thank you.

STATEMENT OF MARK GANNON, PROJECT STAR STUDENT, WATERTOWN HIGH SCHOOL, WATERTOWN, MA

Mr. GANNON. My name is Mark Gannon. I am a junior at Watertown High School. I am 16 years old and currently taking astronomy, where we are doing Project STAR activities. I am also taking English and other required courses. I play football, track, and lift weights.

I am thinking of a career in law or television production. Astronomy may not have a big impact on my future because I have a large problem with math, but astronomy is very interesting to me and I am willing to troubleshoot the math part of it.

It is very different from other science courses I have taken. With the exception of the introduction to physical science courses, most science courses are simply books, opening up the books and memorizing, which I was good at and did well. The astronomy course is more experimentation and actually doing things. I do well in astronomy, but it is much different from the type of memorization course that I am used to. It is more interesting. I simply learn more by doing and I am more aware of what I learn, actually apply it and remember it longer. I do not forget the material right after our test.

I am behind my peers in math and I am taking algebra I, and I now find math and astronomy sometimes complement each other. If I do not understand something in math, I will go to astronomy and maybe understand it there. It is like taking two different math classes with two different teachers.

The math we use in astronomy is different than the math class, but it is much more applicable. I can learn to actually go out there and use it, instead of just reading it in a book and taking it for a fact or memorizing it for a test. In astronomy, although it is kind of a pain in the neck, you can actually go out there and do all these things, and you retain it longer when you realize there is a use for it.

The space program has stimulated my interest in science. People have a curiosity about space to begin with, and I am not really different from anybody else. It is out there and we currently have the means to explore it. If you ask the average person on the street about life on Mars and if they would like to live there for a while, they would probably say yes. Everyone has a natural interest in it. One of the

important things is that if you manage to colonize new worlds the payoff will be tremendous. It stimulates the explorer in people. The explorers in the 1500's were interested in exploring other lands. The trouble is they were not really together in doing it. They were rivals. If they had tried to get together and explore cooperatively, we might not have the international situations we have now.

Space exploration is a second chance. If we can get a multinational effort together, maybe we could cut down on our problems in the future. The benefits would be tremendous economically, culturally, and scientifically. It is definitely worthwhile.

There have been a couple of unique experiments in the courses I would like to tell you about. With the celestial scale that we made in class, I have been able to go out and pick out constellations in the sky and I have been able to tell what stars are in those constellations, sometimes. I have also been able to get a grasp of where we are in the universe. You should know your own house before you go walking around the neighborhood.

Another thing I remember was standing at the bus stop one day after we tracked the setting points of the sun. I looked over and saw the sun setting and noticed it was setting at a different place than before.

I was looking at the people around me thinking: Do you know why the sun is setting over there instead of over here? I knew what was going on and why it was happening. It was very comforting.

I think the role of astronomy in high school should be to introduce students, not just to the memorization on the subject and not just to astronomy, but to a real exploratory and experimental science. Going out and seeing it for yourself, that is the best way to learn. Sometimes it is not applicable in other subjects, but in astronomy it is.

You retain the knowledge longer because you are doing experiments. It may be a little bit more difficult to learn, but it is easier to retain.

The role of astronomy should be to train students in a real science and also to cultivate an interest in astronomy, because that is where everything really lies, maybe not for my children but for my grandchildren, in space exploration and maybe colonization some day.

Thank you.

Senator KERRY. Well, Pamela, Mark, and Rashawn, thank you very, very much for your candor and for taking the time. I know each of you put a lot of energy into those statements today and they were yours, your personal ones, and very heart-feld. And I think all of us appreciate them, and I think we want to say thank you again.

I was going to ask you, Mark, how Watertown did in football, but looking at you I can tell, probably pretty well.

Let me ask each of you one quick question before we close this out. All of you have had a particular experience that somehow made you share an appreciation for science, for space, for the whole series of issues which we have been talking about here today.

Do you think that that is something that we can encourage? Are there things that we could do to make your fellow students feel as much of that excitement? Why would you say you feel it and they do not, or do they feel it? And can we do more to help people feel it?

Does anybody want to tackle that convoluted question?

Mr. GANNON. I have been interested in astronomy since as long as I can remember, but I know most of my friends have not. So when I got to high school, I knew there was an astronomy course. I had a little trouble taking it because of other requirements.

But when I did take it, I found that I had previously had an interest in astronomy, but I noticed that there were a lot of other people in the course who really did not know that much about it, but there was an interest in it. People whom I never thought would want to take another science course ever again were in here taking astronomy.

And so I think it is a very basic interest most people have. And if more courses were available like this, I think they——

Senator KERRY. Has the STAR program made a difference, then?

Mr. GANNON. Yes, I think it has. It teaches not only astronomy, but real science and actually how it works. Like I mentioned when I was speaking, it is not just memorization, but actual learning and doing things.

Senator KERRY. You do not need to answer, Rashawn or Pamela, but if you want to add to that.

Ms. GAY. I know at my school there are many kids even now that are interested in space because they think, okay, there is all the girls in it and all the boys who are really smart in it. Maybe the kids who are not as smart cannot go into it.

But last year when it started opening up at our school for kids to start going to space camp, the kids who went to space camp came back and they told the stories about how fun and exciting it was to go. And then Mr. Blake from the planetarium opened up the young astronauts program, and there is finally someplace where the kids at our school can start getting interested in space and learning about it, and it was being able to learn about it that opened it up, that everyone started getting interested, because before there really had not been a program for it.

And once they started to know about just what is out there and to learn about how everything works and everything, they started getting interested and wanting to learn more. It was like a chain reaction: Learning one thing adds to two things, and so on.

Senator KERRY. Well, the three of you are a living example of what we have been referring to here in a complicated way as infrastructure. You are the future infrastructure and we look forward to trying to guarantee there is going to be a program there for you, and also that the other educational structural pieces are there, whether it is facilities or grants and the adequacy of teachers by virtue of grants and so forth.

And we are going to do our best to do that.

Let me thank everybody for their participation. I particularly want to thank the members of the panels who have taken the time to be here and share their thoughts with us today.

As I said at the outset, this is one of three field hearings in addition to the regular hearings which we will be having on the NASA budget. At the end of the month in Washington, DC, all the administrators of

NASA will be with usto discuss in detail the fiscal year 1989 NASA budget request.

So we will be delving in great depth into the actual allocation issues for each portion of the budget and the choices that we are going to be making. It is my hope, though, and I certainly will go back to Washington, to my colleagues on the committee, and personally circulate to each of them transcripts of this hearing as well as a summary, and try to emphasize to them what I think all of us have come away from this hearing with.

While we opened it up with some questions about the relevance and about the questions of priorities, I think at the end of this hearing, particularly the testimony of the three students, it has to underscore the importance of the choices that we have got to make.

And it leaves us really with no choice. If we are going to be rational about it and sensible and I hope marginally visionary about it, we have to keep this program going and we have to fund it adequately.

And notwithstanding the question of budget restraints if we allow ourselves to be penny wise and pound foolish in this area, we are going to pay the price down the road in more ways than any of us possibly want to describe today or hope to ever have to.

So I want to thank Dr. Fisk and I want to thank you, Mary. I saw a particular note of pride and a smile on your face as you saw the panel testifying. And I want to thank all the rest of you for participating. There is an enormous amount of talent assembled here in this room.

Many of you could have added considerably in a number of fields, and many of you I know would have wanted to. We would welcome the submission of any testimony whatsoever in writing to the committee. The record of this field hearing will remain open in order to receive that.

And I also look forward to having any of you who feel a need to contact the members of staff who are here with me or in Washington with respect to any of the relevant issues that we have either touched on or neglected to touch on in the course of this hearing.

And I would like to thank the Committee staff, particularly Marty Kress, Pete Perkins, Penny Dalton, Linda Morgan, Ann Ward, Emilio Pardo, and Sally Ozell of my own staff, and my own Boston staff. These things do not just happen. They are worked on, planned and put together, and I am very appreciative to them for their efforts.

Thank you all very, very much for joining us. We stand adjourned.

[Whereupon, at 12:20 p.m., the subcommittee was adjourned.]

ADDITIONAL ARTICLES, LETTERS, AND STATEMENTS

STATEMENT OF WILLIAM W. DURGIN, DIRECTOR, AEROSPACE PROGRAM, WORCESTER POLYTECHNIC INSTITUTE

WPI would comment on the importance of the role of spa ce science in the education of science and engineering students. Our undergraduate program requires substantial project activity of each student as they complete degree requirements. One of these, the interactive qualifying project, must address the interrelationship of technology and society while another, the major qualify project, constitutes a thesis in the primary discipline. Finally, the sufficiency, demands that a thematically coherent program of study in the humanities be completed.

The U.S. space program has provided substantial and significant foci for our project efforts in recent years. At our Washington Project Center, for example, students work with NASA scientists in studying the history of mission planning and forecasting of technology requirements for projected missions. Collaboration in such scholarly endeavors provides meaning to our efforts which is simply not available otherwise.

NASA sponsors undergraduate programs of extraordinary educational value. A recent example was the national space suit glove design competition wherein schools competed first by proposal and then by design among the selected finalists. The technical substance and importance to NASA of the effort resided in the necessity of developing better gloves for operation at the higher operating pressures of the space station. Competition is a marvelous stimulant to students already intrigued with the space program while the educational substance lay in the systems engineering effort required. A similar program, ongoing at the present time, is the Universities Advanced Space Design Program which addresses systems engineering issues associated with post-space station mission technologies. This program provides incomparable capstone design experiences to undergraduates in which their basic course of study can be integrated in an imaginative manner to address technology development issues.

In another avenue, the Small Experiment Payload program allows students to design and build flight experiments taking advantage of the microgravity environment. More than 250 WPI students have participated in the design and building of space experiment packages. One payload is presently ready for flight and includes experiments on fluid behavior in the absence of gravity and zeolite crystal growth. A second payload incorporating an artificial gravity platform for low gravity fluid studies, a microgravity combustion ignition experiment, and an ionospheric wave propagation experiment is under development. Such flight opportunities, available at low cost, provide incomparable education experiences by providing both scientific substance and significant consequence to undergraduates desiring to pursue aerospace careers.

Undergraduate interest in space is extraordinarily high at this time. Providing opportunity for project work through and in association with NASA is an incredible opportunity for us to attract outstanding scientists and engineers to the space program. The benefits are also manifest in other ways. For example, undergraduate project work of this sort easily leads to graduate study on the part of participating students, helping to provide a continuous stream of teachers and researchers in the future. The graduate research, itself, has high intrinsic value to our nation. At WPI, for example, two graduate-level research efforts that grew out of undergraduate projects, oxygen recovery from Ilmenite and zeolite crystal growth, have enormous technological and economic implications. Needless to say, space science forms the basis for the scholarly activity of many faculty. By providing opportunity for participation in space research, NASA widens the participation of U.S. scientists.

We have witnessed other impacts as well. For example, a local elementary school student has developed an experiment to be flown in the WPI package. Each of us has enjoyed the enthusiasm of our audiences when talking to classes in area schools about space engineering and the importance of science.

Also rewarding has been our interactions with engineering professionals from the many regional firms that participate in America's space program. We believe they have benefited from the research results of our student projects and faculty efforts, and we know we have benefited from their expertise and interests in our program.

STATEMENT OF DR. FAROUK EL-BAZ, DIRECTOR, CENTER FOR REMOTE SENSING, BOSTON UNIVERSITY

THE NEED FOR CONTINUED EARTH OBSERVATIONS FROM SPACE

The American space program has pioneered looking at the Earth from space during the mid 1960's. Photographs obtained by the Gemini and Apollo astronauts proved very useful to scientific investigations in numerous disciplines. Images obtained in the seventies by Skylab and Landsat were followed by data taken in the early 1980's by the Space Shuttle. Acquisition and distribution of such data has helped to place the United States in the forefront worldwide in many fields such as crop forecasting, geologic exploration, investigations of the oceans and forests, and monitoring of the environment, to name a few.

Agricultural crop forecasting significantly benefited from repeated coverage by Landsat multi-spectral scanner (MSS) data. This was particularly true in the Large Area Crop Inventory Experiment (LACIE), which emphasized crop inventories in the American Midwest. There, vast areas are used for the mechanized raising of the same crop. The 80-meter resolution of the MSS system was ample for such investigations. However, for the same procedure to be used in less developed countries, higher resolution is required to distinguish between different crops in small plots of land.

The utilization of such knowledge from space is essential in these countries because of the scarcity of statistical data and/or the trained personnel to collect and analyze the information. This becomes more significant when we take into account the problems of food production in most of the less developed world. In planning to acquire and distribute high-resolution data for use in crop forecasting in the less developed countries, the United States would be helping to better plan for the future and to avert potentially disastrous food shortages.

Geologists have perhaps been the most consistent users of data from space. They recognized from the onset that images of the Earth taken from high altitudes can show important structural trends, regional stratigraphic relationships, and signatures of the spectral characteristics of economic rocks and minerals.

Data from the Landsat MSS and its later improvement, The Thematic Mapper (TM) with 30-meter resolution were utilized in geologic mapping worldwide. The United States naturally benefited most from such use. Examples abound in the location from space data of new sites for oil and gas, concentrations of gold and silver in altered rocks, and deposits of copper and similar ore minerals. Considering the expanding demands for energy and mineral resources, the need for acquisition of better and more specialized data for the geologists will continue in the future.

Investigations of the oceans from space vastly improved our knowledge of the planet's water system. Internal waves, between layers of water with varying densities, were first recognized in images from space. Similarly, ocean currents, eddies, and plumes were explained—based on their study in space photographs. Further knowledge of the Earth's oceans is required to better develop fisheries and better understand ocean-land interactions.

The field of forestry also benefited greatly from applications of space-born data. Observations from space pointed to areas of the world's forests which are threatened either by natural causes or from over-harvesting of trees. Furthermore, space-based data promise to help in identifying tree species for better and more detailed inventories of the forests. This is essential to keeping a proper balance between the use and the preservation of forested areas of the Earth.

Perhaps the most significant impact of images from space was to heighten the interest in protecting the environment by people worldwide. The first such images were those of the Earth obtained in December 1968 by the Apollo Mission 8 from the vicinity of the moon. These crystallized the view of the whole Earth as a single, fragile unit in an otherwise, dark, cold, and uninhabitable vastness.

Since then space observations have been widely used in support of environmental conservation efforts. Year after year we receive new evidence of such utility, to the

extent that some were admitted as evidence in court trials of environmental pollution cases.

Much remains to be done in this field of environmental conservation, and observations from space can play a significant role. For example, the Boston Harbor is presently threatened by unchecked pollution that will eradicate its fisheries and render its beaches useless. Remote Sensing instruments and methodologies could be applied to monitor this water body, pin point problem areas, and investigate water dispersion patterns. This knowledge would help decision-makers establish what needs to be done in the short term and plan for future action in the long term.

The role of images from space in education should not be neglected. Photographs of the Earth from orbit have already been most successfully used in text books throughout the educational system in the United States, starting with the first formative years of child development. These photographs portray an interesting, realistic and most informative view of the Earth that compliments maps and other data.

Similarly space-borne data are very useful in scientific research. This is true even in such fields as archaeology, which emphasizes the detailed work on localized sites. Archaeologists are using such photographs to establish the environmental conditions of previous human habitation sites, to discover routes of trade, and to delineate burial and other sites. In the New England states an effort was initiated to use remotely-sensed data to survey archaeological sites, particularly in National Parks. Such efforts should be encouraged and augmented by further, more detailed observations from space.

Today, no one would question the need for continued observations of the Earth from weather satellites in geosynchronous orbits, 23,000 miles above the Earth. These satellites have given us unique perspectives of the circulation of air in the Earth's atmosphere and of water in the oceans. They continue to help us in short-term weather forecasting.

Future observations must emphasize long-term forecasting of weather patterns and the establishment of climatic trends. The extended droughts in Africa in 1968–1973 and 1979–1984 present a case in point. Because they caught the world by surprise, they caused unacceptable loss of life and untold misery in the Sahel, south of the Sahara.

These droughts have caused dangerously low levels of the water of Lake Nasser behind the High Dam at Aswan, and threatened the lives of 50 million Egyptians. We could be better prepared for such events if we plan to utilize the available technology in the acquisition of data for long-term global weather forecasting.

Future efforts must also take into account the need for the utilization of space data for map making. This would only be possible if stereo images were obtained to allow interpreting the terrain in three dimensions. The Large Format Camera, which was test flown on the Space Shuttle in 1984 is an advanced system that allows the acquisition of such data. Efforts should continue to assure the utilization of such a camera from space and the development of similar systems for future operations.

The French satellite SPOT as well as Soviet space missions are now producing stereo images from Earth orbit, at the time when no United States missions are doing so. This situation must be remedied if America is to continue to lead in the exploration of space.

Spinoffs from the space program have benefited mankind in numerous ways and improved many aspects of our lives. The basic investments have already been made by the United States. It would be tragic if America surrenders the leadership in space observations of the Earth to others. This is particularly true since these observations provide the most tangible benefits of high-technology applications not only to citizens of the United States but also to people worldwide.

STATEMENT OF DR. TOM CHANG, DIRECTOR, CENTER OF EXCELLENCE IN THEORETICAL GEO/COSMO PLASMA PHYSICS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE

ABSTRACT

An outline of the recent activities at the MIT Center of Excellence in Theoretical Geo/Cosmo Plasma Physics is provided. This is followed by a plea for adequate federal support for basic theoretical research in space sciences.

I. Recent Activities at the MIT Center of Excellence in Theoretical Geo/Cosmo Plasma Physics

Nearly everything in space is composed of collections of electrons and other charged particles, commonly known as plasmas. The physics governing the motion of such plasmas in the external magnetic fields which are omnipresent in the cosmos is the prime domain of the science of plasma physics. A new Center of Excellence in Theoretical Geo/Cosmo Plasma Physics was recently established at MIT, partially supported by the federally funded University Research Initiative Program. The goal of the Center is to foster theoretical investigations of the plasma phenomena in the solar-terrestrial and cosmic surroundings.

We are currently embarked upon a variety of plasma physics problems as they are manifest in the space environment. These include charged particle energization phenomena in space together with associated effects: the precipitation of electrons in the mysterious auroral displays observed near the polar regions of the earth and other planets, intense electromagnetic radiations which contribute to local radio noise, and radio emissions resulting from the relativistic acceleration of charged particles in active galactic nuclei and quasi-steller objects in the distant cosmos. In addition, we are concerned with the ubiquitous wave turbulence in solar-terrestrial and cosmic plasmas, the intense electric fields that are commonly detected in space and the study of the streaming plasmas from the sun or other stars called the "solar wind" and its interactions with the magnetospheres of the planets.

Ours is a unique program of theoretical research in geo/cosmo plasma physics. The Center operates as a single cohesive unit of scientists from several disciplines interacting effectively with one another and with groups from external ongoing experimental research programs. It has not been the purpose of the Center to carry out routine data analysis and the like. Our approach had been to interact with the experimental groups to delineate from the analyzed data those problems which have no ready-made, physical explanations and to focus our efforts on the solution of such new problems by effectively utilizing the interdisciplinary nature of the Center.

To foster and expand the horizons of the newly acquired theoretical understanding of our space surroundings, the Center sponsors semi-annual symposia and workshops on the various sub-disciplines of space physics research. Experts in these disciplines are invited to such scientific gatherings to interact with each other, to share their ideas, and significantly to deliver tutorial lectures to the interested students and space physicists of other disciplines for the purpose of ensuring the perpetuity of these dynamic research activities.

Unfortunately, due to the current federal budgetary constraints, the funding of the Center has experienced some draconian cuts. It is hoped that such basic research activities as conducted by our Center can be preserved. Basic theoretical space research which requires only relatively small amounts of monetary support as compared to the huge budgets that generally are required to carry out the mission-oriented experimental space programs must be carefully preserved and nurtured, or else in effect, we shall be eating our own seed corn.

There are also direct implications for the technological base and future health of the U.S. economy from developments in X-ray astronomy. The advanced X-ray optics are being adapted for commercial applications in X-ray lithography, with potential applications for super-fast computer chips. Detectors developed for X-ray astronomy have found their way to a host of applications in areas such as diagnostic medical instrumentation, pharmaceutical research, basic biological and chemical research, non-invasive quality control and automated manufacturing equipment, fusion research, and security inspection devices. Our society will also derive educational benefits from AXAF. For example, 10-20 new Ph.D's can be expected to complete their thesis research each year using AXAF. We project that AXAF will be utilized by approximately 1000 astronomers every 2 or 3 years (nearly 700 astronomers have used the data from the 2-1/2 year Einstein mission).

This addresses, to some extent, the question of big science vs. little science. The cost of the AXAF development - approximately $1B in current year dollars - certainly represents a significant investment. It is expensive to develop a high resolution X-ray telescope and to place the entire observatory in space. Once there, however, AXAF will follow the traditional route of a national facility for astronomy. The observing time will be allocated on the basis of scientific merit, and the large number of astronomers using AXAF will carry out a vigorous mix of both small and large research projects.

Because of the tremendous scientific potential, the National Academy of Sciences' Astronomy Survey Committee chose AXAF as the number one priority major new initiative for the 1980's for all of ground and space-based astronomy and astrophysics. National facilities such as our powerful ground-based telescopes and our space-based Great Observatories will place us in a unique position to leap forward in our understanding of the Universe. Multiwavelength studies are clearly needed to unravel many of the mysteries which stare back when we peer into our telescopes. Moreover, the history of astronomy assures us that the new power provided by AXAF will lead to serendipitous glimpses and then detailed studies of entirely unanticipated phenomena. By starting AXAF now, we will be moving ahead with an outstanding scientific mission which has been thoroughly studied and readied for development. As a nation, we have embraced the goal of excellence and leadership in science and space research and exploration. In this context, we must proceed with AXAF.

II. A Plea for Adequate Support of Theoretical Research in Space Sciences

Traditional space science technology has focused on mission-oriented hardware and instrumentation, as well as on the collection of physical data. Sponsoring agencies generally have not provided sufficient funding for the detailed analysis and theoretical interpretation of the accumulated data. This has been compounded further by the fact that too often the experimentalists have been more interested in the collection of data than its analysis. As a consequence, theoretical research efforts in the space sciences have been pushed off to neglected corners as inconsequential appendages of the otherwise mammoth experimental or hardware programs.

Consequently, our current theoretical understanding of the complex physical phenomena that occur in the space surroundings is grossly inadequate. On the other hand, it is of paramount importance that the theoretical understanding of the physics of space grows with the planning and execution of any future space missions so that the process of collecting useful, new data is productively guided by the phenomenology and physics discovered from our previous experience.

Recognizing this gross inadequacy, the National Aeronautics and Space Administration and the Air Force Office of Scientific Research through its University Research Initiative Program have established centers of research in theoretical space sciences. Not specifically connected with other mission-oriented satellite and spacecraft programs, these centers are allowed to interact freely with the various research establishments and spacecraft programs for the purpose of identifying the many unsolved puzzling physical phenomena in space sciences and to attempt to unravel these puzzles using the currently available theoretical tools in space physics; and if the existing tools are inadequate, then new tools are to be manufactured. Unfortunately, the level of monetary support that is made available to these research groups is generally minuscule and patently inadequate. Without exaggeration, the total support for such theoretical efforts probably amounts to less than one hundredth of one percent of what has been committed to the corresponding experimental endeavors.

While we recognize the realities implicit in the current Government budgetary situation, we should like to point out that some fundamental changes should be made to protect research of this description and caliber from the ravages of the annual or bi-annual funding cycle. Our own experience demonstrates that the time scale for understanding some of Nature's more challenging puzzles is measured in years, not months. We must adopt a long-range vision if we hope to do more than scratch at the surface of ignorance.

To assure that the United States will continue to strive for a leading role in the scientific conquest of space and to extend our knowledge to the understanding of the solar-terrestrial surroundings and the cosmos beyond the heliosphere, the federal government must endeavor to provide adequate funding to the established theoretical centers in space sciences, lest we be left far behind the Soviets as well as our European and Japanese colleagues irrespective of the total number of satellites and spacecraft that are projected to be launched in the future.

Support of basic theoretical research must not be tied down with the satellite or spacecraft programs, nor should the administration of the theoretical efforts be left to the experimentalists.

STATEMENT OF WILLIAM A. M. BURDEN, PROFESSOR, ASTROPHYSICS AND PRESIDENT OF THE AMERICAN ASTRONOMICAL SOCIETY

The Space Science program of the United States is of central importance to astronomy, and as the President of the American Astronomical Society I am pleased to be able to submit these comments. Our Society, founded in 1899 when our country was a minor player on the world astronomical scene, has seen the steady growth of American astronomy to its preeminent position today on the world scene. Before commenting on the present condition of space astronomy, however, it is illuminating to identify the key elements in that growth.

In the earliest years of our society, one must be struck by the vigor and boldness with which American observatories built the largest telescopes in the world. The culmination of this phase of growth was the construction of "The Glass Giant of Palomar," the great two-hundred-inch telescope that is still an impressive instrument, fully in the vanguard of modern discoveries. The significance of these developments for space science is clear: many of the great unsolved secrets of the universe need large collecting areas to gather in the faint trickle of light that holds the vital clues.

A second motif is equally important in the work of American astronomers: the aggressive exploitation of new technologies. Even before the Second World War, electronic techniques for measuring the light from the stars were a completely American development; radio astronomy was started by two pioneering radio engineers; then, after the war, the US pioneered the use of rockets and satellites to make astronomical measurements. The Soviets shocked us with their launch of the Sputnik, a technological achievement of great significance, but they were helped to be first by a timid and poorly-organized American satellite program that gave the Soviets a temporary lead by default. Very quickly, however, there was a vigorous American response, and the first successful satellite put in orbit by the United States, the first Explorer, led to van Allen's discovery of the radiation belts that bear his name. This was the first genuine scientific discovery to be made by means of a satellite, and marked the beginning of a long line of dramatic advances in science by the United States.

It is especially appropriate that a hearing on "Space Science Today" should be held here in Boston, because several key developments in space astronomy were led by local groups of space scientists here in Massachusetts. These included the discovery of x-ray sources, which led to the science of x-ray astronomy, the discovery of cosmic gamma radiation, the conception and execution of the x-ray observatories Uhuru (SAS-1) and SAS-3, and the largest of the early x-ray observatories, the Einstein satellite. The local astronomers certainly must have heard with great pleasure the news that the AXAF telescope has been proposed as a new start in the 1989 budget, and I would like to address that issue next.

The National Academy of Sciences/National Research Council issued the report of the Astronomy Survey Committee in 1982, in a document entitled "Astronomy and Astrophysics for the 1980's." That committee, under the chairmanship of Professor George Field, laid out an ambitious but realistic plan for the development of astronomy over the current decade. The Council of the American Astronomical Society reviewed the recommendations in that report, and endorsed them enthusiastically. Two key lists of projects were outlined, the first being a list of four major projects, two in space and two on the ground, listed in priority order, while the second presented a list of seven "moderate" projects, having a scale about a factor of ten smaller in cost compared to the major missions.

The highest priority among the major missions was assigned to the building of a large x-ray telescope facility in space, and it is the AXAF project that meets that recommendation. The astronomers of our society will surely applaud this progress. The x-ray community in the US, including the large contingent of x-ray astronomers here in Massachusetts, will be eager to see this new start implemented. They have waited through a harsh decade since the termination of the Einstein x-ray observatory for this successor project, watching powerlessly as their colleagues in Japan, Europe, and the Soviet Union move into a dominant position in the field. Competition is a good thing in science, but in this case the American scientists, who had invented the field, lacked the means to compete in this scientifically rewarding endeavor. All of American astronomy will now benefit by pressing the AXAF mission to a successful conclusion.

The second list in the Astronomy Survey Committee report, the "moderate missions" was headed by a general proposal to enhance substantially the "Explorer" class satellites. These are the lineal descendants of van Allen's original Explorer, and are intended to be a continuous program of innovative, forefront, exploratory missions whose smaller scale allow greater flexibility and adaptability to new directions of astronomical research. Our country has experienced bitterly the consequences of backing a single large space project, and diversity is essential. The proposed 1989 budget contains a significant enhancement of the Explorer line, and this will give a new thrust to a most successful program.

These reactions to the new budget are, however, the response of the scientists to their needs. One should always be able to answer the question that society poses for us: Why should these abstruse and expensive investigations be supported at this time? In my view, there are two classes of answer to this question. The first is a practical response. When the United States was supporting a vigorous and expanding scientific program on a broad front, our high technology sector grew spectacularly on all fronts, giving our country a forefront position in the world in practically every area of technological products. Discovery and development marched together. As the level of scientific support levelled off, and actually became a declining fraction of our gross national product, that dominant position became increasingly eroded, not to a catastrophic degree yet, but if the trend continues the future is not bright. Is there a cause and effect relationship? That is more difficult to prove, but the empirical facts are there. Diversity and excellence in science march together with preeminence in technology.

When viewed at the level of an individual discipline, one can still identify the contact points between the pure science (such as astronomy) and the practical, industrial sector. A large project, such as AXAF, makes multiple demands upon industry. The scale of construction becomes larger, the tolerance becomes more demanding, the sophistication of the materials and components becomes greater, and a broad front of industrial activities are stimulated. Examples abound to illustrate the fact. The low-dose x-ray inspection machines at airports were developed by x-ray astronomers, the devices in space that survey for illegal bomb tests use x-ray astronomy-derived equipment, the satellite relay stations use cosmic radio sources to calibrate their antennas, and x-ray tomography (and magnetic resonance imaging) use mathematical analysis techniques developed by radio astronomers years before. Even at the basic level of human affairs, one can see that the quality of jobs that are created to build these great projects emphasize high technology as a general rule, and it is easy to see the industrial stimulation that occurs in the vicinity of the institutions that direct these projects. The smaller missions, such as the Explorer class of satellites have a unique

stimulatory effect as well. Their demands on local industry are of a more specialized nature, generally in completely new technological areas. This means that new high-tech companies are spawned to meet the more specialized demand, and the industrial base is broadened. The Explorer program provides a number of examples of this type of entrepreneurial encouragement.

There is a second, and more philosophical, reason for supporting basic science, with space astronomy as the present example. Astronomy has broadened our view of the universe enormously, a process that started with the ancient Greeks, proceeded through the revolution of Galileo and Newton, received a dramatic broadening with the discovery of the expanding universe, and now through the means of space astronomy reaching to study new and previously undreamed-of objects such as black holes and neutron stars. One cannot deny that the astronomical projects are expensive, but they yield exciting and thought-provoking rewards. The astronomer reaches for answers that are fundamental: Where did the universe come from? How did our solar system form? What is the fate of the universe? What are the fundamental laws that govern the universe? Are there other civilizations on planets of other stars, or are we alone? These questions may not be immediately practical, but the thinking person must be moved by the possibility that we can, after all, seek such answers. We in the United States enjoy the material benefits of technology, but we have always placed a high value on intellectual achievement as well. Here in Massachusetts, the wide variety of first-rate universities bears direct witness to the American commitment to education and learning.

Finally, let me return to the historical aspects with which I began. American astronomy realized its accomplishments by pressing vigorously on two different fronts. Our leaders framed bold initiatives in building the world's largest telescopes, and at the same time the American astronomers led the world by rapidly and aggressively incorporating the latest technological developments in their equipment. The new initiatives for space astronomy, and for space science in general, are a continuation of these traditions, and with the help of the American people those traditions will be upheld, to the pride and benefit of all.

STATEMENT OF DR. WILLIAM M. IRVINE, PROFESSOR, PHYSICS AND ASTRONOMY, UNIVERSITY OF MASSACHUSETTS AT AMHERST

The impetus for much of space science, including the instrumentation necessary for space research, very often develops from ground-based astronomical studies. In particular, the extremely weak nature of the signals analyzed by astronomers as they study distant objects in the Universe has driven the development of extremely sophisticated, high technology instrumentation, much of which has subsequently found important commerical and/or defense-related applications.

An example of this synergism between science and technology, and between universities and the private economic sector, is provided by the University of Massachusetts at Amherst. The University operates the Five College Radio Astronomy Observatory (FCRAO), where the principal instrument is the largest radio telescope of its type in North America. This 14-meter-diameter telescope is used 24 hours a day, 7 days a week, throughout much of the year by scientists and students from Massachusetts and around the world. During the 1986-87 observing year, for example, astronomers and their students from some 25 institutions in the United States and 6 foreign countries used the facility to study problems in most of the major areas of current astronomical research, including planetary science, star formation, astrochemistry, the late stages of stellar evolution, and the dense interstellar medium, in studies encompassing both our own Milky Way Galaxy and external galaxies. Typically between 15 and 20 graduate students per year use the telescope as part of their dissertation research prior to entering careers in the academic world, national laboratories such as those maintained by NASA, the high technology electronics industry, or positions in computer science. The scientific literature is enriched by approximately 100 papers a year produced by the Observatory staff and visitors.

In order to maintain its pioneering role in this area of science, the University has established a reputation for world leadership in the development of extremely sensitive electronics and quasi-optical techniques for use at these very highest radio frequencies (the wavelength region extending shortward of 4 millimeters). As radio astronomers have pushed to higher and higher frequencies, commercial applications have followed in their wake. An example of this in western Massachusetts is the Millitech Corporation in South Deerfield, founded by former FCRAO Director and Professor of Astronomy Richard Huguenin, which is pioneering the development of commercial applications for instrumentation originally conceived for astronomical research. As such applications grow, the private industrial base develops to the point where it can undertake projects that are beyond the scale that are easily accessible to a university group. One important result has been collaborative proposals to NASA forinstruments to be flown on planetary missions in which the University ofMassachusetts or other universities are the prime contractors with responsibility for the science and Millitech Corporation is a sub-contractor which actually builds much of the instrumentation. Other collaborative work has led to the development of instruments for measuring ozone and other critical constituents of the Earth's stratosphere.

Another synergistic university-industrial relationship is exemplified by the close cooperation over a number of years between the FCRAO at the University of Massachusetts and the Electronic Space Systems Corporation (ESSCO) in West Concord, Massachusetts. Both the Observatory's 14 meter diameter telescope and its protective enclosing radome were manufactured by ESSCO. By sharing in the development of electronics for operating the telescope and in the actual erection process, the University and ESSCO were together able to create this facility at a cost far below actual market value. Continued interaction has provided both a showpiece in its home state for ESSCO and the opportunity to take advantage of University expertise on new technological developments. A recent outgrowth of this cooperation has been the replacement of the original radome fabric with a new material which dramatically increases signal transmission at extremely high radio frequencies and thus significantly increases the power of the telescope for astronomical research. The new radome structure, which incorporates material developed by W.L. Gore and Associates, Inc., is a first of its kind and has potentially very important applications for any radio or radar facility operating in the short millimeter and sub-millimeter wavelength regions. As in the past, close cooperation in both materials testing and in installation made possible a project between these in-state neighbors which would have been very difficult to achieve in any other way.

To return to the science carried out at FCRAO, consider some recent successes and their relevance to space research. In addition to coordinating worldwide radio astronomical observations of Halley's Comet, University of Massachusetts' astronomers F. Peter Schloerb and William M. Irvine used the 14 meter telescope to make the first direct measurements of the outflow velocity of gases evaporating off the cometary nucleus into the surrounding atmospheric coma. They also succeeded for the first time in convincingly detecting a nuclear constituent after its evaporation, hydrogen cyanide, and in monitoring the production of this constituent throughout the comet's approach to and recession from the Sun. The radio telescope is also used for studies of photochemistry in the atmospheres of the planets Venus and Mars. This technique provides not only the abundance but also the distribution with altitude in the upper atmosphere for carbon monoxide, which is produced by the effect of sunlight on the principal atmospheric constituent (carbon dioxide). By observing variations between day and night and across the disk of the planet, information is gained on wind systems in the upper atmosphere. It is important to recall that the stimulus for investigations of potential ozone depletion as a result of human activities in the Earth's stratosphere was originally provided by studies of the photochemistry of Venus. Such radio astronomical studies are important precursors to NASA's Mars Observer and CRAF missions.

The interaction between activities by NASA's Astrophysics Division and ground-based radio astronomy is exemplified by the several projects underway at the University comparing data acquired by the infrared astronomy satellite (IRAS) with observations obtained or underway at FCRAO. Areas of interest include star formation, the violent processes by which young stars or protostars evacuate material from their immediate vicinity in the form of energetic outflows, the distribution of cold interstellar material in the Galaxy, and the intrinsic nature of many of the sources uncovered in the IRAS survey. A separate but exciting project has been the participation of FCRAO in continental-wide very long baseline interferometry (VLBI) at the highest frequencies which this technique has yet employed. On the air simultaneously with observatories in California and Arizona, these FCRAO data have provided the highest resolution on the sky every obtained in the history of astronomy by any astronomical technique, and have obtained exciting new results on the detailed structure and dynamics of quasars and explosive galactic nuclei. Later this month a new experiment will be tried in which observatories in Sweden and Japan will also participate. To obtain even higher resolution in the future, the use of orbiting facilities such as the NASA Quasat Project will be necessary.

Life Sciences at NASA also has a role in these studies. Life began on Earth only after some ten billion years or so of previous Galactic history for the elements and compounds incorporated into terrestrial biology. Studying the evolution of this chemical complexity in the solar system and in the more distant space between the stars provides the necessary background to understanding the subsequent evolution of life on the Earth. An exciting recent result in this area has been the first detection in interstellar space of a molecule containing the element phosphorus, by University of Massachusetts astronomer Lucy Ziurys. Phosphorus plays a critical role in terrestrial biochemistry, far greater than might have been anticipated from its limited cosmic abundance. Other new organic constituents of interstellar clouds are being discovered regularly by scientists at the University of Massachusetts and elsewhere, increasing the background of knowledge necessary to understand the prospects for the existence of life throughout the Universe.

In the future, this University team is planning to extend spectral coverage of their observations to even higher frequencies, into the so-called sub-millimeter region between the radio portion of the spectrum and the infrared. Plans for an Institute for Sub-millimeter Astronomy and Technology at the University of Massachusetts are currently being developed. In addition, the University is participating with the Smithsonian Institution's Smithsonian Astrophysical Observatory in a proposal for a Sub-Millimeter Array Telescope. This would be an extremely powerful astronomical instrument operating in this largely unexplored frequency region, and would provide important precursor information to space missions toward the end of this century such as the Large Deployable Reflector (LDR) under consideration by NASA and the Far-Infrared Space Telescope (FIRST) project of the European Space Agency.

It is perhaps not out of place to mention that one University of Massachusetts astronomer has been named a Co-Investigator on the Soviet Unions' PHOBOS Mission to Mars, scheduled for launch in July of this year. The long and continuing hiatus in NASA Planetary Missions has stimulated increasing participation by American scientists in European and now Soviet space missions. It is an unfortunate commentary on the current situation in this country that such projects are "the only game in town".

International Physicians for the Prevention of Nuclear War, Inc.

"We shall require a substantially new manner of thinking if mankind is to survive" ALBERT EINSTEIN

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March 7, 1988

The Honorable John Kerry
U.S. Senate Commerce Committee Hearing
Boston Museum of Science

Dear Senator Kerry,

For the last decade, most of the interest in space science has been for military purposes. The people of the world are at greater risk of nuclear annihilation today because of the sophisticated weapons that are being developed by space science. International Physicians for the Prevention of Nuclear War would like to use the occasion of the Subcommittee's hearing in Boston to tell you about our project to use space science for health and peace.

Three years ago, doctors in our federation, which links the nearly 180,000 members of the physicians movement against nuclear war in 55 countries, began to discuss the uses of space for health. Could powerful new technologies be used to enhance health in the world? Could the nuclear superpowers of the world cooperate to improve the health of all the peoples of the world? The concept of Space for Health emerged. Last year we were able to begin a specific project, SatelLife, when Academician Evgueni Velikhov, the Vice President of the Soviet Academy of Sciences, offered to provide IPPNW with a "launch" to put a communications satellite in orbit.

The first phase of SatelLife has evolved through a series of international meetings. During the IPPNW Congress in Moscow last June amateur radio experts from the United States and space scientists from the Space Research Center of the USSR, working with IPPNW health specialists from all over the world agreed on some basic concepts. Phase I would develop a telecommunications system that uses satellites to link health programs in the developing world with supporting programs in industrial countries. There remained many particulars to be decided on.

During the Space Future Forum which was held in Moscow in October to commemorate the thirtieth anniversary of Sputnik, the SatelLife group reconvened. During three working sessions that I chaired, we came close to agreement on the outlines of a plan and a schedule. Three working groups were created to assemble detailed plans. In Boston, a group of telecommunications experts, who volunteered to assist SatelLife, designed a satellite for packet-radio communications. This system would permit a very simple and inexpensive ground station at a remote location to send many pages of text, two or three times per day, to a satellite in polar orbit. The satellite would store the information, and send it back to earth at a new location on command. Here a small receiver attached to a personal computer would accept the text. The ingredients of this electronic mail system could be put in place very quickly.

In Geneva, a group at the World Health Organization was to tackle the difficult problem of how to use modern communications technology to enhance the effectiveness of health programs around the world. For example, who could benefit from an electronic mail system that could link Geneva, to Kinshasa, to the smallest village in Zaire? The first obvious choices were the child survival activities which are trying to immunize all children in the world by 1990, and the AIDS program of WHO. But WHO continues to study other applications for the future.

In Moscow, IKI, the Space Research Center, was to examine how to launch and support a packet-radio satellite. Could the satellite be transported to the Mir space station? And once there, should it operate on its own or with a tether? What kind of broadcast frequencies would have to be available to operate a packet-radio system of electronic mail for health programs?

In less that two weeks, these working groups will reconvene at the Merieux Foundation in Annecy, France, to amalgamate the plans. We hope to be able to launch a satellite and inaugurate a WHO electronic mail system before the end of 1988--the World Health Organization's fortieth anniversary year.

IPPNW would appreciate an opportunity to share the results of our upcoming discussion with the Subcommittee. We hope that as the Subcommittee continues to review space science in the world that it will focus its attention on how space science can contribute to both health and the prevention of nuclear war.

Sincerely,

Anthony Robbins

Anthony Robbins, MD
for IPPNW